Copyright 1945, by the AMERICAN SOCIETY OF NAVAL ENGINEERS

JOURNAL

OF THE

AMERICAN SOCIETY OF NAVAL ENGINEERS

VOL. 57. NOVEMBER 1945. No. 4.

The Society as a body is not responsible for statements made by individual members

COUNCIL OF THE SOCIETY

(Under whose supervision this number is published).

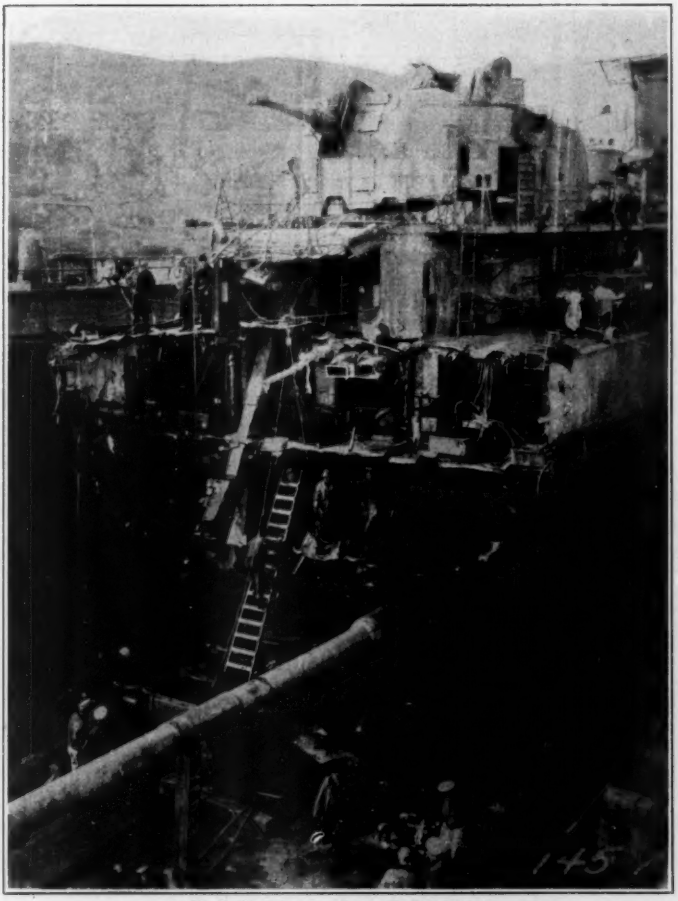
Rear Admiral E. W. MILLS, U.S.N.
Mr. W. H. BAILEY.
Rear Admiral A. M. CHARLTON, U.S.N.
Commander H. E. DAVIS, U.S.C.G.
Lieut. Commander E. G. KINTNER, U.S.N.R.
Captain P. F. LEE, U.S.N.
Mr. FRED SELLS.
Captain H. C. SEXTON, U.S.N.
Mr. G. B. WARREN.
Rear Admiral F. J. WILLE, U.S.N.
Captain F. W. WALTON, U.S.N.

U. S. NAVY BATTLE DAMAGE PICTURES FROM WORLD WAR II.

BY COMMANDER ERNEST C. HOLTZWORTH, U. S. NAVY.

The following photographs comprise the first of four series which the Society will publish in four consecutive issues of the JOURNAL. They have been selected from those in the files of the Bureau of Ships, Navy Department and all are official U. S. Navy Photographs. They portray typical examples of damage incurred by U. S. warships in action against the enemy. None has been published previously. A brief description of the circumstances in each case is included with the caption.

Photo 1: The U.S.S. *Abner Read* (DD526) in dry dock at Adak in the Aleutian Islands on 21 August 1943. This ship, a 2100-ton *Fletcher* class destroyer, struck and detonated a drifting Japanese mine while making a right turn at the inshore end of her patrol station while screening the anchorage off the island of Kiska. The center of impact was well aft on the port quarter. Within four minutes the aftermost 70 feet of stern broke off and sank. *Abner Read* was towed to Adak and placed in dry dock where the photograph was taken. The clean line of the break is praticularly noteworthy and is typical of the experiences of several light U. S. warships which have suffered major detonations at the extreme bow or stern. In this case it will be noted that the port shaft was broken clearly but that the starboard shaft remained intact. It is of interest to note that the starboard propeller, the after strut and the forward strut were stripped clear of the shaft by the stern as it sank. The after end of the starboard shaft was bent downward at an angle of approximately 5 degrees, placing the extreme after end, at the location of the propeller nut, approximately 10 feet below the base line. Prior to docking it was necessary to rotate the shaft through 180 degrees to permit entrance of the vessel into the floating dry dock and placement on the blocks. *Abner Read* was never in danger of sinking despite the loss of a substantial portion of her stern.



U. S. S. "ABNER READ" (DD526).

Photo 2: The U.S.S. *Hambleton* (DD455) in dry dock at Casablanca, North Africa on 19 January 1943. This ship, of the 1630-ton class, was torpedoed while at anchor off Cape Fedala, French Morocco, on the night of 11 November 1942. She was struck on the port side in way of the forward engineroom by a shallow-running electric submarine torpedo. The detonation opened the forward engineroom and after fireroom to the sea and destroyed approximately sixty per cent of the hull girder. Fortunately, calm weather permitted towing to Casablanca without breaking in two. At Casablanca one of the most unusual and ingenious repair jobs of the war was done. After first raising and repairing the only adequate floating dock (a two months job) *Hambleton* was placed in it on 19 January 1943. In dock a section of the hull, approximately 50 feet in length and including the forward engineroom and after fireroom, was removed. The bow section, being unstable, was ballasted and rigidly secured to the dock and the stern section was floated forward and redocked. The two sections were joined together by a fairing section approximately 13 feet in length. She was undocked on 8 May. Necessary engineering connections were made and on 9 June *Hambleton* departed Casablanca with steam from the forward fireroom supplying the port engine in the after engineroom. Acting as an escort vessel and at times making good a speed of 18 knots, she arrived at Navy Yard, Boston on 26 June for rebuilding. She was returned to service on 15 November 1943.

U. S. S. "HAMBLETON" (DD455).

Photo 3: The fire in the hangar of the U.S.S. *Princeton* (CVL23) during the early afternoon of 24 October 1944. At the time, *Princeton* was operating with a fast carrier striking force to the eastward of Luzon. A Japanese 250 kilogram bomb struck the flight deck, passed through the hangar and detonated at about the second deck above the after engineroom. A raging fire was started in the hangar among fully gassed aircraft, six of which were armed with torpedoes. About 20 minutes after the hit, the first of a series of heavy explosions occurred in the hangar. These continued for about 20 minutes. About one hour later the *Birmingham* (CL62) came alongside to port and passed hose lines aboard and some personnel. Three destroyers and the *Reno* (CL96) assisted at various times on the starboard side. As a result, most of the fire was extinguished during the next hour. The photo was taken by *Birmingham* when the most intense fire remaining was in the after elevator pit. The photo is a view looking into the hangar through a port quarter roller curtain door. The officers in the hangar are directing a 1½-inch stream of water into the after elevator pit. The wreckage seen is the remains of an F6F airplane. The opening to the right of the roller door was caused by an explosion in the hangar which blew out the light weight hangar side plating, exposing to view the piping and heavy locker.

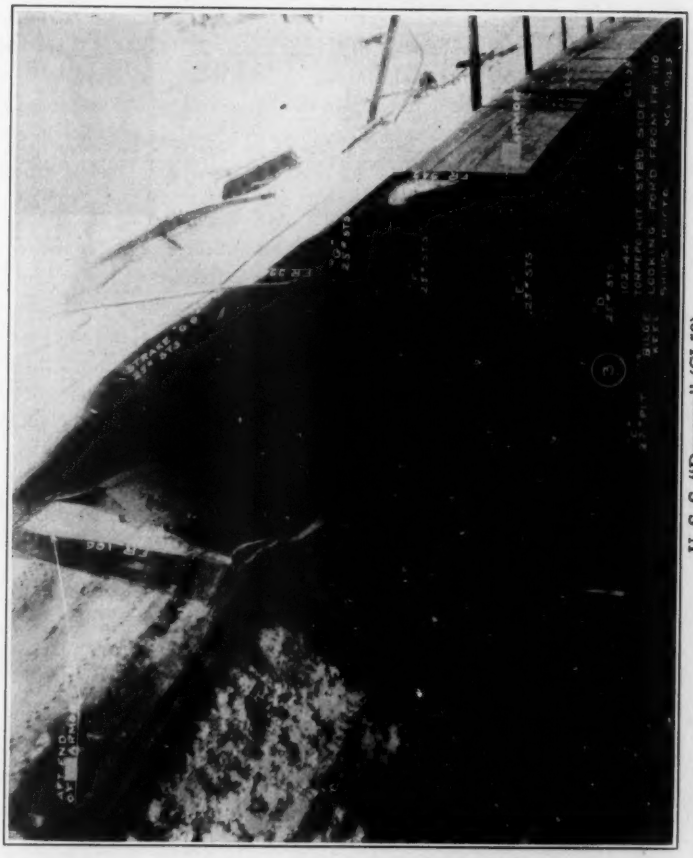
Fires aft of the hangar were never extinguished. Later in the afternoon a mass detonation occurred of bombs stowed in a main deck space aft of the hangar. This explosion caused numerous casualties on *Birmingham*. At dusk *Princeton* was sunk by torpedoes from *Reno*, for tactical reasons. At the time, the hull was still intact below the second deck.

U. S. S. "PRINCETON" (CVL23).

Photo 4: Fighting fire in the hangar of the U.S.S. *Intrepid* (CV11). On 25 November 1944 *Intrepid* was a unit of a fast carrier striking force operating to the eastward of Luzon. Shortly after 1200 the ship went to General Quarters. A few moments later she was struck by the first of two suicide planes. It crashed the flight deck somewhat aft of amidships causing a gasoline fire on the flight deck. The single bomb carried by the plane detonated in the gallery, just below the flight deck. Nineteen fully gassed planes, armed only with ammunition, were in the hangar and these were ignited. While fire-fighting was in progress the second plane crashed the flight deck well aft. Prior to the crash it released a bomb which penetrated to the hangar and detonated in the midst of the firefighters. The second crash greatly increased the intensity of the hangar fire and started a bad conflagration among planes parked aft on the flight deck. Despite a large number of casualties to fire-fighters, the fires were controlled and extinguished in about two hours. The photo shows a team manning a 2½-inch hose line with a 12-foot applicator. The hangar fire is almost extinguished. Note the quantity of fire-fighting water on deck, the remains of a fighter plane and the blackened and charred appearance of overhead structures. This scene is typical of conditions caused by bad hangar fires in aircraft carriers.

U. S. S. "INTREPID" (CV11).

Photo 5: Torpedo hole in U.S.S. *Denver* (CL58) while in dock at Espiritu Santo, November, 1943. During the night of 12-13 November 1943, *Denver* was a unit of a task force covering the movement of other forces to Empress Augusta Bay, Bougainville Island. Just prior to dawn a torpedo plane attack developed during the course of which a single aricraft torpedo struck *Denver*. The torpedo detonated upon impact at or just below the lower edge of the armor belt on the starboard side about 4 feet forward of the after bulkhead of the after engineroom. The after engineroom flooded immediately and the after fireroom flooded slowly through open piping systems and electric cable bulkhead stuffing tubes. The armored third deck over the point of impact was ripped open at seams and butts and some spaces on that deck were flooded. The starboard outboard shaft (below the hole in the shell) was bent sharply and only the port outboard shaft remained in operation. Although *Denver* could make about 4½ knots with 100 Rpm. on the one remaining shaft, she was taken in tow by the U.S.S. *Sioux* (AT75). Eventually a speed of better than 8 knots under tow was attained using 135 Rpm. on the one operable shaft. She went first to Tulagi and thence to Espiritu Santo where she was placed in dock and the photo taken by *Birmingham*. It will be noted that the two aftermost armor plates are missing. The armor bolts were pulled through the shell and the plates dropped, or were wrenched off. This is typical of the behavior of armor plate of moderate thicknesses, having been noted in several other cases of cruiser torpedo damage. The hole in the shell is bounded at the top by the armored third deck and at the after end by armored bulkhead 106. At Espiritu Santo a temporary patch over the hole in the shell was installed. The port unit was found intact and relatively undamaged, except for immersion. It was placed in operation with relative ease, although bearings for turbines and reduction gear were renewed as a precautionary measure. *Denver* returned to Navy Yard, Mare Island with Nos. 3 and 4 shafts in operation.



U. S. S. "DENVER" (CL58).

Photo 6: Torpedo hole in U.S.S. *Independence* (CVL22) while in dock at Navy Yard, Pearl Harbor in December 1943. Late in the afternoon of 20 November 1943 the fast carrier striking force of which *Independence* was a unit underwent an air attack while west of Tarawa. While making a high speed left turn *Independence* was struck by an aircraft torpedo which detonated upon impact about 16 feet aft of the after bulkhead of the after engineroom on the starboard side. The starboard heel from the turn resulted in a shallow point of impact, somewhat below the first platform. Damage at the after starboard corner of the after engineroom caused that space to flood in 2½ minutes. The after fireroom flooded slowly through open piping systems and electric cable bulkhead stuffing tubes. The starboard outboard shaft vibrated violently and before the unit could be stopped the shaft broke just forward of the flange which is just abaft the stern tube. It will be noted in the photo that the fracture occurred below the point of impact. The port shaft remained in operation and Rpm. was increased to 288, giving a speed of about 13½ knots with the one shaft. The armored third deck was damaged somewhat more extensively than on *Denver* (the point of impact was closer to the deck than for *Denver*). In the photo the damaged portion has been replaced by temporary plating. This was done at Funafuti prior to arrival at Navy Yard, Pearl Harbor. At Pearl Harbor, the after engineroom was made tight in dock and machinery cleaned and treated with tectyl. *Independence* then proceeded to U. S. Navy Drydocks, Hunter's Point for permanent repairs.

U. S. S. "INDEPENDENCE" (CVL22).

U. S. NAVY DEVELOPMENTS IN UNDERWATER CUTTING.

By Bela Ronay and Cyril D. Jensen.*

Underwater cutting of metals has been practiced by the Naval Service in connection with salvage and other operations for several decades. Two methods, the arc-oxygen and the oxy-hydrogen processes have been in competition throughout this time. The first method originally involved the employment of carbon electrodes in the form of tubes or bars through which oxygen passed and required a D. C. source of power capable of delivering at least 600 amperes at 50 volts. The oxy-hydrogen underwater cutting process was developed through evolution from the older oxy-acetylene cutting procedure used in air. In course of the evolution, hydrogen replaced the acetylene as fuel and the cutting flame was stabilized by surrounding it with an envelope of air. Oxy-hydrogen torches incorporating the latter improvement are being produced commercially today by several reputable manufacturers and have been regarded until quite recently, as the most satisfactory device for the underwater cutting of metal. Meanwhile, owing to the lack of improvement in equipment and method of application, the arc-oxygen procedure came to be regarded as antiquated when compared to the oxy-hydrogen process.

Confronted with the need for a simple effective means for underwater cutting, the Navy Department decided early in 1942 to develop the arc-oxygen process to meet the requirements of War's demands. The decision was based partly on the desire to eliminate the need for the highly inflammable hydrogen, the fuel used with the oxy-hydrogen process, in that hydrogen is a powerful explosive within a wide range of dilution and is hence a most undesirable deck cargo in times of war. A further undesirable feature of the oxy-hydrogen procedure is that the nature and design of the torch tip employed prevents its effective use in a mass of wreckage. Therefore, the Bureau of Ships authorized

* Engineering Experimental Station, Annapolis, Md.

an investigation to modernize arc-oxygen cutting. The investigation resulted in:

(a) New electrode design,
(b) New torch design,
(c) Simplification of the technique for using the new materials,
(d) Standardization of the new procedure,
(e) Improved safety features in applying the procedure and
(f) Performance equal to that obtainable with oxy-acetylene in air.

The modernized arc-oxygen underwater cutting procedure, as adopted by the Navy Department for its purposes, employs covered steel and ceramic tubes as electrodes. The newly developed electrodes are employed with the normally available 300 ampere capacity welding generators or transformers. The oxygen consumption has been considerably reduced from that found necessary with the earlier type of electrodes, while the cutting rate has been many times increased. The power requirement has been approximately halved. The torches now manufactured to accommodate the new type electrodes are not only safe to handle but permit rapid removal and replacement of electrodes independent of the degree of visibility. In the development of new techniques for arc-oxygen cutting, particular attention was devoted to the improvement of safety features for divers. This becomes apparent in the design of the accessories, the required use of a disconnecting switch in the welding circuit, and by the proper dissemination of information concerning these safety features.

Modernization of the arc-oxygen procedure for underwater cutting has been performed at the U. S. Naval Engineering Experiment Station, Annapolis, Maryland. Field tests of the new materials, equipment, and procedure were conducted mostly at the Experimental Diving Unit and Deep Sea Diving School, Navy Yard, Washington, D. C., and at the U. S. Naval Training School (Salvage) Pier 88, New York, N. Y.

The arc-oxygen method of cutting metals is based on the same principle as that employed in oxy-acetylene cutting. In the latter, the metal is first locally preheated to incandescence by means of the oxy-acetylene flame. When incandescence is reached, a high

velocity jet of oxygen is impinged upon the preheated spot. The oxygen jet performs the double duty of oxidizing or burning the core of the preheated portion and removing the products of combustion. As the oxy-acetylene cutting torch is moved along the intended line of cut, the diffused heat from the first spot, augmented by the heat supplied by the oxy-acetylene flame, continuously advances the incandescent spot in preparation for the action of the oxygen stream. In arc-oxygen cutting, preheating is performed by the electric arc maintained between the material to be cut and the cutting electrode. Since the heat energy available in an arc is much greater than that of an oxy-acetylene flame, preheating with the arc-oxygen method is practically instantaneous. Therefore, the instant the arc is established the high velocity oxygen stream is admitted to impinge upon the preheated spot where the same phenomena occur as given above for oxy-acetylene cutting. Advancing the electrode along the intended line of cut while the electric arc is continuously maintained results in the uninterrupted succession of preheat, oxidation, and removal of the burnt metal.

The arc-oxygen process is being employed using either D. C. or A. C. power in the arc circuit. D. C. power, which is employed at straight polarity, i.e., electrode negative, is preferred for the reason that it is easier to maintain the arc when the electrode is the hot cathode; also, for underwater operations, it is much safer than A. C. More skill and attention is required with A. C. power in that during each electric cycle both the current and the voltage drop to zero.

Continuing the analogy between oxy-acetylene and arc-oxygen cutting, it is evident that in the latter procedure the arc replaces the oxy-acetylene flame and electric power is substituted for the acetylene fuel. The tip of the oxy-acetylene cutting torch is merely a multiple orifice nozzle which is outside the combustion zone, and in fact kept cool by the gases flowing through it. Thus the life of the tip of the oxy-acetylene torch is not affected by use as long as it is unharmed by mechanical injury. In arc-oxygen cutting the electric arc heats both poles. As the tip of the electrode is one of the poles of the arc, it too is being kept at incandescence and thus exposed to the effects of heat and oxidation.

Steel Tube Electrodes.

Since copper base alloys and cast iron do not oxidize readily, the early users of the arc-oxygen method employed brass and cast iron electrodes. However, the investigation showed that steel, though readily oxidizable from incandescence, is more suitable by reason of its higher melting point. The steel tube core electrodes specified by the Navy Department for underwater cutting by means of the arc-oxygen process are 5/16 inch O.D., 14 inches long with a somewhat less than ⅛ inch bore. These dimensions were evolved empirically and represent the optimum disposition of the available metal for the purpose intended.

The investigation further showed that in order to obtain the desired effects as regards easy starting and maintenance of the arc, it is mandatory that the electrodes be covered. At the present, three types of coverings are being produced commercially on the above cores. One type of covering is produced by extrusion. The composition of this covering is similar to that applied to welding electrodes intended for use in all positions at straight polarity D. C. or with A. C. These electrodes are waterproofed after processing by dipping, the waterproofing material being a thermoplastic lacquer. Another producer processes the steel tubes by multiple dipping, introducing the waterproofing lacquer in the last bath where it also serves as the binder for the mineral components of the covering. A third method of processing the steel tubes is by applying wrappers of plasticized cellulose tape. The plasticized tape is fully waterproofed and, therefore, processing with this material is performed in a single operation. The tape is applied cigarette fashion around the steel tubes. The role and the performance of all of the above coverings are identical. The covering must be consumed at a slower rate than the core in order to form and continuously maintain a protecting thimble around the arc; it also must liberate gases to form the bubble wherein the arc is maintained. The covering serves as an electrical insulator, even in the wet condition, to safeguard the diver-operator in the event of accidental body contact while cutting and to prevent arcing from the side of the electrode when working in confined quarters. The covering must be concentrically consumed in cutting to permit restarting the arc, as in welding, should that be necessary. The consumed covering must not form slag on the material being cut in that should slag be deposited

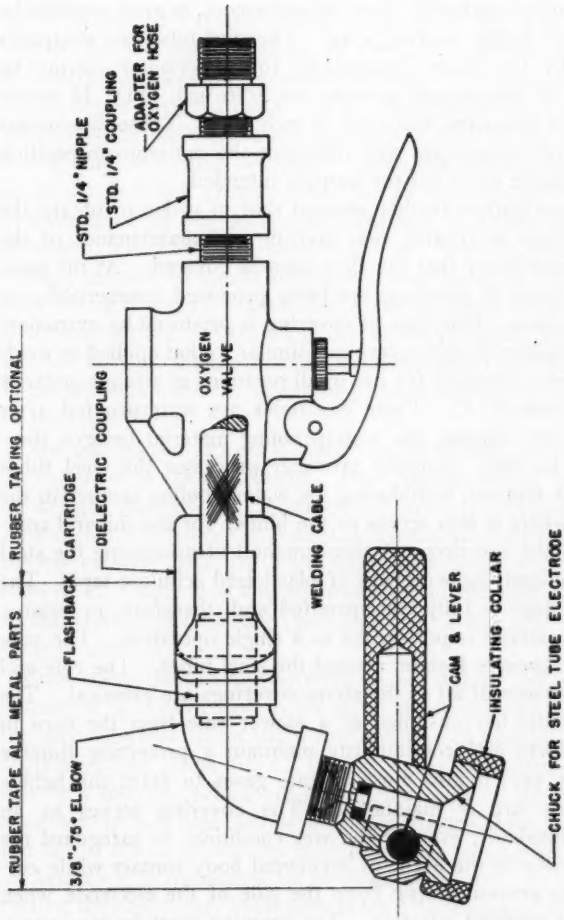


FIG. 2. CAM ACTION ARC-OXYGEN TORCH
(LEFT SIDE VIEW)

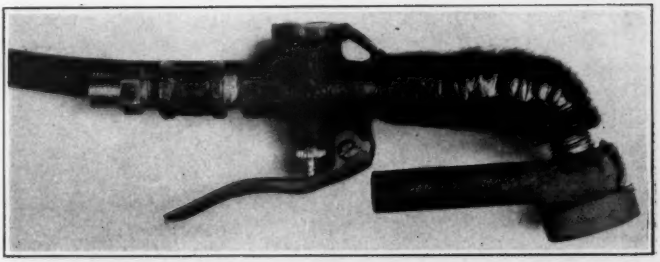


FIGURE 1.—ARC-OXYGEN UNDERWATER CUTTING TORCH.

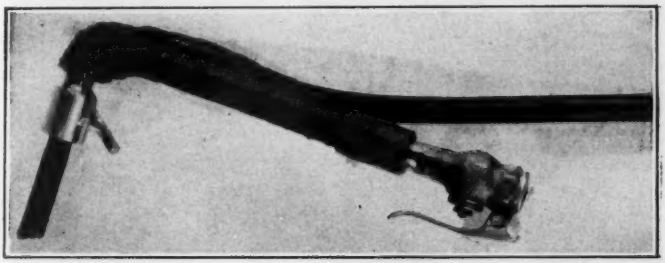


FIGURE 9.—TORCH USED FOR REMOVING AUSTENITIC WELD METAL.

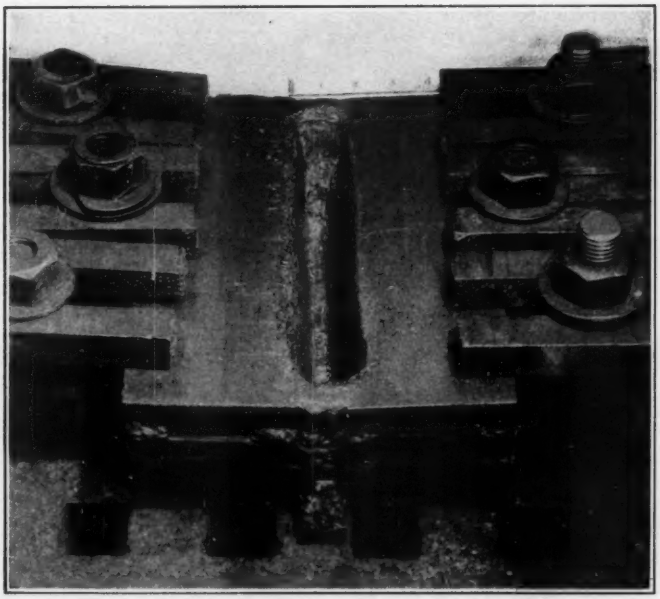


FIGURE 10.—AUSTENITIC WELD METAL REMOVED IN 3-INCH PLATE ASSEMBLY

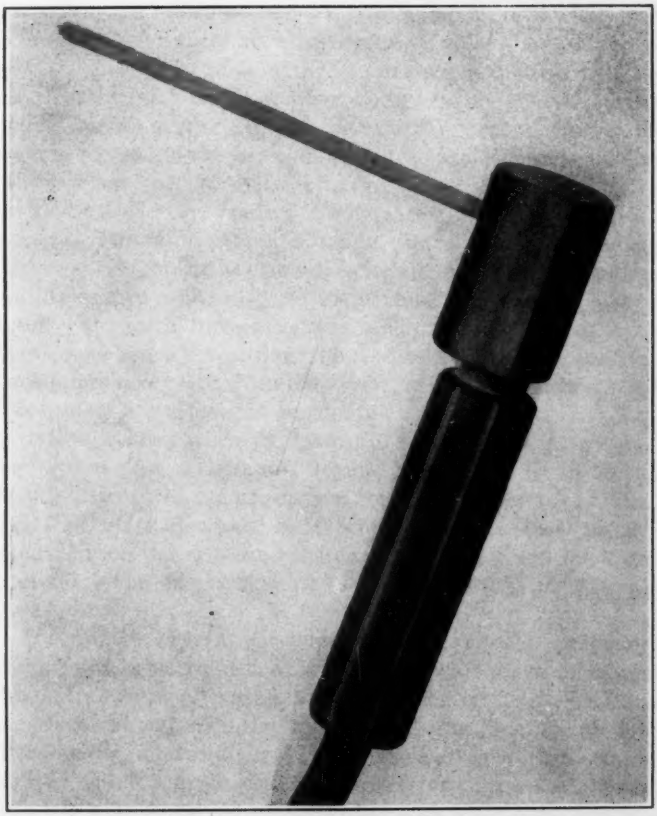


FIGURE 12.—INSULATED UNDERWATER ELECTRODE HOLDER.

in the groove further oxidation would be prevented until the slag is removed.

Regardless of the type of covering used, the service life of a covered, tubular steel underwater cutting electrode averages one minute. It is evident, therefore, that torch design must provide for quick and effortless removal and replacement of electrodes. The torch designed for arc-oxygen cutting, as shown on Figure 1, consists essentially of a quick opening oxygen valve and the electrode carrying chuck or head. The negative terminal of the electric circuit is attached to the head of the torch. Between the oxygen valve and the head of the torch is a dielectric coupling which serves to shunt out the oxygen valve from the electrical circuit and, thereby, renders it both safe for use as a grip and prevents it from deterioration due to electrolysis. The drawing, Figure 2, also shows the cam action locking device, and the rubber washer against which the end of the tube is pressed in engagement. The torch further contains a flashback arrester as it has been found that when cutting with steel tube electrodes occasional backflashes take place when the technique is not properly applied. The flashes are somewhat similar to those which occur in oxy-acetylene welding when the torch tip is accidentally dipped into the molten pool. The extra flexible lead, generally 10 feet in length attached to the arc-oxygen torch, is usually of 1/0 size. The lead cables, furnished in 50 foot lengths, are size 0 and 2/0 depending on the distance between the generator and the diver-operator. The oxygen line used is the standard ¼ inch oxygen hose.

The rate of oxygen consumption is not critical; satisfactory cutting can be performed within a fairly wide range of oxygen flow. However, applying less than the optimum rate may slow down the operation and, requiring more careful attention, may tire the diver-welder unnecessarily. Using more oxygen than can be utilized within a given plate thickness is of course sheer waste. The following tabulation presents plate thickness-oxygen pressure ratios which were found to be most economical:

Plate Thickness, Inch	*Oxygen Pressure, Psi.*
¼	20
½	30
¾	40
1	50
More than 1	75 or more

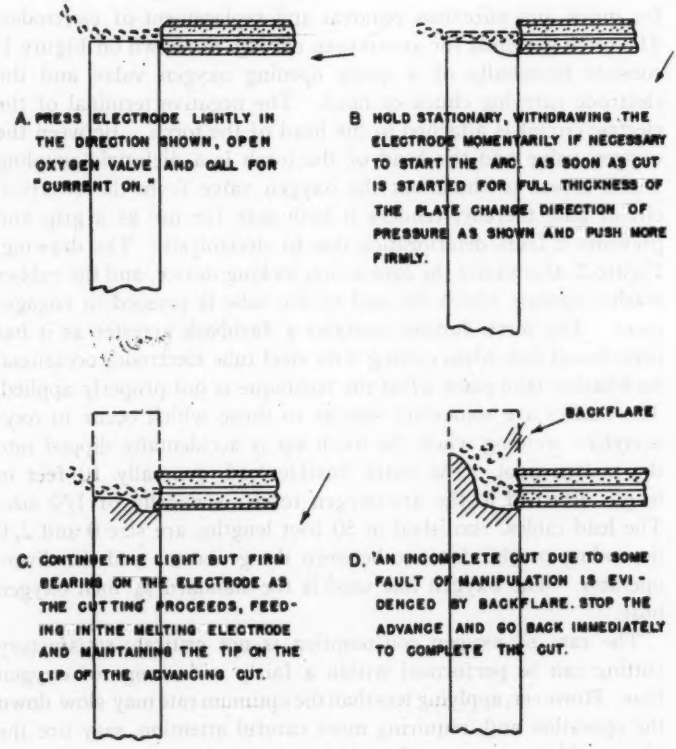

A. PRESS ELECTRODE LIGHTLY IN THE DIRECTION SHOWN, OPEN OXYGEN VALVE AND CALL FOR "CURRENT ON."
B HOLD STATIONARY, WITHDRAWING THE ELECTRODE MOMENTARILY IF NECESSARY TO START THE ARC. AS SOON AS CUT IS STARTED FOR FULL THICKNESS OF THE PLATE CHANGE DIRECTION OF PRESSURE AS SHOWN AND PUSH MORE FIRMLY.
C. CONTINUE THE LIGHT BUT FIRM BEARING ON THE ELECTRODE AS THE CUTTING PROCEEDS, FEEDING IN THE MELTING ELECTRODE AND MAINTAINING THE TIP ON THE LIP OF THE ADVANCING CUT.
BACKFLARE
D. 'AN INCOMPLETE CUT DUE TO SOME FAULT OF MANIPULATION IS EVIDENCED BY BACKFLARE. STOP THE ADVANCE AND GO BACK IMMEDIATELY TO COMPLETE THE CUT.

FIG. 3. UNDERWATER CUTTING OF STEEL
ARC - OXYGEN METHOD - STEEL TUBE ELECTRODES

The above values do not include the pressure drop which obtains in a hose more than 50 feet in length, nor for the mean head of water above the zone of cutting. To compensate for the static head the following empirical formula is used: Topside pressure in p.s.i. $= 0.445 \times H + P$, wherein H is the head of water in feet and P, the pressure given in the above tabulation. No formula is applicable to compensate for loss of pressure due to hose lengths in excess of 50 feet in that the pressure drop varies with the size and condition of the hose and the number of kinks in the line.

In modernizing the arc-oxygen method all efforts were concentrated to simulate the simplicity of oxy-acetylene cutting in air. Accordingly, the technique developed for the arc-oxygen process, the so-called "drag technique" consists merely of pressing the electrode against the advancing lip of the cut. The only task resembling electrode manipulation involved in arc-oxygen cutting underwater is to hold the electrode at all times as near perpendicular to the metal being cut as practicable. As the electrode is being consumed at a fairly rapid rate the diver-operator must compensate for the gradual shortening of the electrode by exerting pressure simultaneously forward and inward as the cut advances. Figure 3 illustrates graphically the above-described technique. The outstanding virtue of the above simple technique is that no attempt is required to hold an arc as in welding. Inasmuch as the modernized procedure for arc-oxygen cutting consists of merely dragging the electrode as it cuts through the steel, it is called "The Drag Technique".

In cutting ¼ inch or thinner plate the above procedure must be modified. There are two applicable modifications. One calls for reducing the pressure to barely touching the metal ahead of the cut. The other method, which is of particular value when the visibility is poor, is to point the electrode at 45 degrees back toward the already completed cut. Thus the effective thickness to be cut is increased and cutting can be performed applying the normal pressure required with the Drag Technique.

Punching a hole in steel is readily accomplished with steel tube electrodes. The process is rapid and the technique extremely simple. The procedure is fully illustrated on Figure 4. By this method 3 foot diameter steel shafting has been pierced without difficulty.

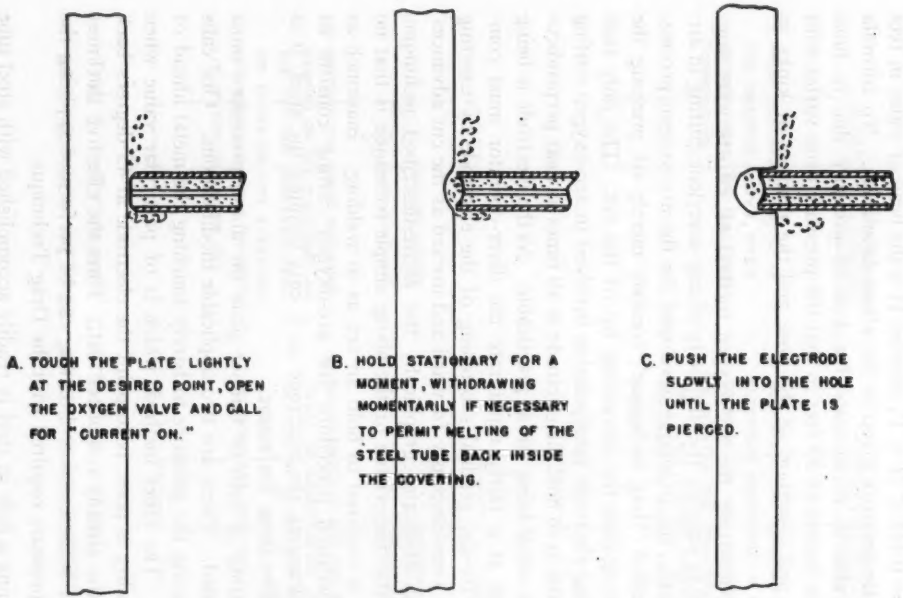

A. TOUCH THE PLATE LIGHTLY AT THE DESIRED POINT, OPEN THE OXYGEN VALVE AND CALL FOR "CURRENT ON."
B. HOLD STATIONARY FOR A MOMENT, WITHDRAWING MOMENTARILY IF NECESSARY TO PERMIT MELTING OF THE STEEL TUBE BACK INSIDE THE COVERING.
C. PUSH THE ELECTRODE SLOWLY INTO THE HOLE UNTIL THE PLATE IS PIERCED.

FIG. 4. PUNCHING A HOLE THRU A PLATE
ARC - OXY-GEN METHOD — STEEL TUBE ELECTRODE

The arc-oxygen method of underwater cutting, employing steel tube electrodes, is adaptable to cutting steel in air. The applicable technique for all thicknesses of plate may be either the "drag technique" as described above or a short arc technique as in welding. The cutting rate is rapid and the neatness of the cut is intermediate between those obtained with the oxy-acetylene and the carbon arc methods.

The above descriptions pertain to cutting steel. In addition, the arc oxygen procedure is also applicable to cutting, in air or underwater, cast iron, stainless steel and the non-ferrous metals. However, as the latter materials do not oxidize readily the cutting process is slow in that it becomes mainly that of melting. It was found that the "Drag Technique" is not applicable. The investigation further showed that in cutting brass or bronze, air may be substituted for oxygen but that in cutting cast iron some advantage is derived through retaining the oxygen. By reason of the apparent sluggishness of the metal, which melts only in the immediate sphere of the arc, it is necessary to melt out the metal in layers which requires constant manipulation of the electrode in and out of the cut. This manipulation also helps to push out the molten metal which is not blown out by the oxygen or air stream. However, when the above metals to be cut are only ¼ inch thick or less, they can be parted by arc-oxygen cutting, employing the first of the techniques given above for parting thin steel plates.

The performance of arc-oxygen cutting electrodes is determined by cutting underwater steel plates of ¼ inch, ½ inch, and 1 inch thickness. The requirements for suitability of 14 inches long, 5/16 inch diameter, 0.112 inch bore steel core underwater cutting electrodes are based on obtaining the following minimum cutting rates and cut-burnoff ratios:

MINIMUM REQUIREMENTS.

Plate Thickness Inch	*Oxygen Pressure p.s.i.*	*Cutting Rate Inch/Min.*	*Cut-Burnoff Ratio*
¼	20	20	1.5
½	30	15	1.0
1	50	8	0.75

The term Cut-Burnoff ratio given above is applied to define the ratio of the length of the cut obtained for each inch of the

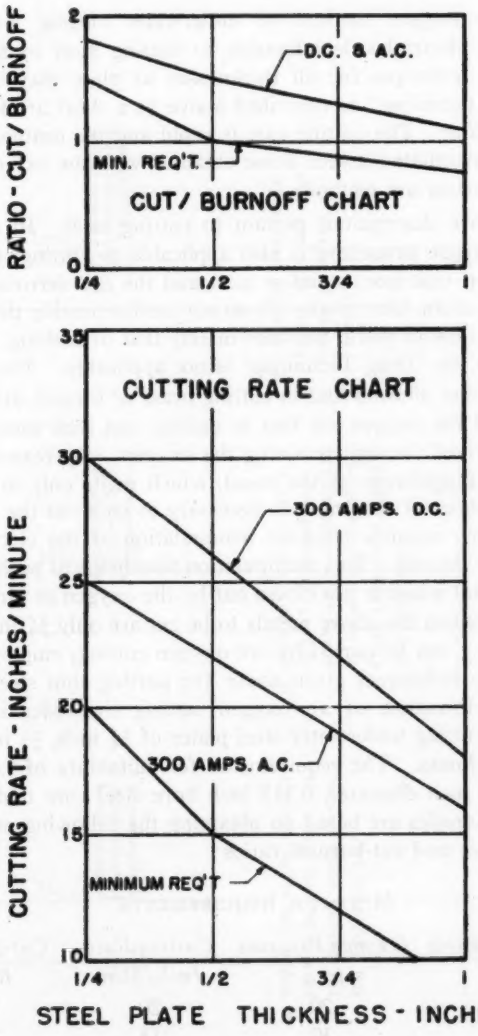


FIG. 5. UNDERWATER CUTTING - ARC - OXYGEN METHOD. 5/16" DIA. STEEL TUBULAR ELECTRODES WITH A COMMERCIAL EXTRUDED COVERING.

electrode consumed. Under Laboratory conditions the cutting rates and cut-burnoff ratios are much more favorable than indicated in the above tabulation. Figure 5 gives typical results obtained in the course of inspection tests. Thus a single electrode when consumed to a 2 inch stub will cut, under laboratory conditions, 21 inches of ¼ inch plate or 13 inches of 1 inch plate, all in a period of slightly less than a minute.

Analyzing the performance of covered steel tube underwater cutting electrodes the following advantages become evident:

(a) Simple technique, ease of operation.
(b) Rapid rate of cutting.
(c) Neat, trim cuts.
(d) Power requirement within the capacity of a 300 ampere welding generator or transformer.

Disadvantages:

(a) Short electrode life, requiring frequent replacement.
(b) Low cut-burnoff ratio.
(c) Narrowness of kerf removed renders inspection difficult.

The short life of the covered steel tube electrodes is a serious disadvantage under many conditions occurring in underwater cutting operations. Likewise, the neat, narrow kerf removed by these electrodes may be a handicap when the diver-operator inadvertently fails to cut through at one or more points. The narrowness of the gap prevents an easy, direct method of locating the uncut part by feeling, which is the only method of inspection available in underwater cutting. To overcome the above shortcomings and as a complement to the covered steel tube electrodes another type has been developed, namely, the covered Ceramic tube, underwater, arc-oxygen cutting electrode.

Ceramic Tube Electrodes.

The core of the Ceramic tube electrode is, as the name implies, a ceramic material composed of highly refractory, stable oxides. This non-metallic substance was chosen for the following reasons:

(a) Being a high grade refractory, its melting point is materially higher than that of steel.
(b) Being composed of stable oxides, it is not affected by the oxygen stream.
(c) It is an electrical conductor.

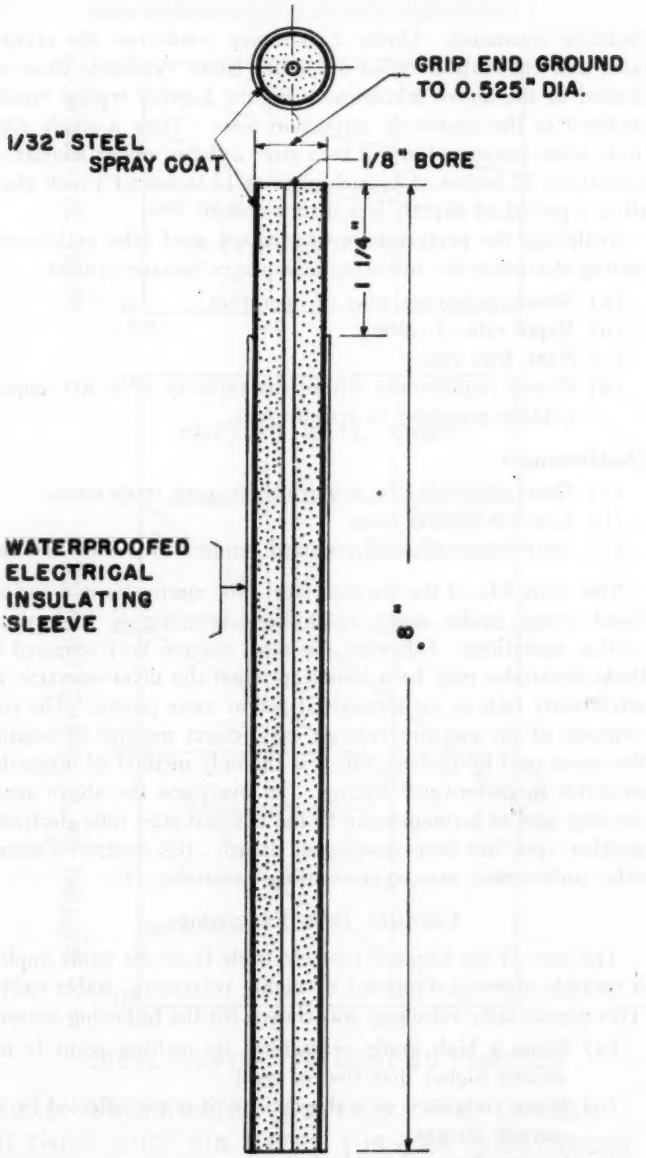


FIG. 6. THE CERAMIC TUBE ELECTRODE

The core of the Ceramic tube electrode is ½ inch in diameter, 8 inches long with an ⅛ inch bore. The core tube is processed first by a high temperature heat treatment which renders it resistant to thermal shock. The inherent brittleness of the ceramic product is almost fully compensated by the 1/32 inch thick mild steel shroud which is applied for the full length of the electrode by metal spraying. Finally, the tube is wrapped by an electrical insulating sleeve and further covered with waterproofing. One end of the steel shroud, for the length of 1¼ inches is ground to 0.525 inch diameter to serve as the grip end, as shown on the sketch on Figure 6.

Ceramic tube electrodes are employed with the same power sources as the steel tube material. However, while the power input is approximately the same for the steel and the ceramic tube electrodes, the latter should be operated at 350 amperes at 30 volts D. C., straight polarity or A. C. Although the bore of the Ceramic tubes is slightly larger than that of the steel tubes, the same oxygen pressures are applicable with both types. The cutting technique used with the ceramic tube electrodes is a modification of that developed for the covered steel tubes, and differs in the respect that the Ceramic tubes are applied with a light touch. The kerf removed in cutting with Ceramic tube electrodes is not as clean as with steel tubes, however, it has the merit of width. For ½ inch plate and less the diver-operator is able to reach through with his gloved hand to inspect the fullness of the cut. Typical cutting rates and the burn-off ratios obtained in inspection tests of Ceramic tube electrodes are shown on the graph on Figure 7. The head of the arc-oxygen cutting torch originally developed for use with the 5/16 inch diameter covered steel tube electrodes is detachable and is replaceable by another whose bore accommodates the Ceramic electrodes.

The specified minimum performance for Ceramic electrodes is as follows:

Plate Thickness Inch	*Oxygen Pressure p.s.i.*	*Cutting Rate Inch/Min.*	*Cut-Burnoff Ratio*
¼	20	20	1.5
½	30	15	1.0
1	50	8	.75

A direct comparison between the cutting-rate graphs on Figures

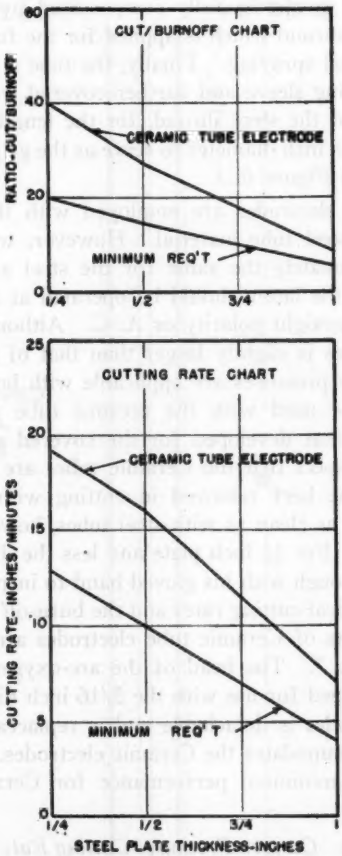


FIG. 7. TYPICAL PERFORMANCE CHART, CERAMIC TUBE ELECTRODE

5 and 7 should not be made owing to the fact that the rates shown on Figure 5 do not include time to change electrodes and to regain the arc. For a comparative study of the cutting rates obtainable with the steel tube and the ceramic tube electrodes the logical time interval to be used is 12 minutes which is the approximate average life of a ceramic tube electrode. During the course of 12 minutes of cutting with steel tube electrodes it may be assumed that approximately 8 electrodes will be consumed, the remaining time being used in changing electrodes and regaining the arc. On the basis of the above conditions Figure 8 is presented with the understanding that it is an approximation only as the skill of the operator and the adversity of the diving conditions play a most important part in the rate of underwater cutting.

A review of the performance graphs on Figure 8 indicates that the ceramic tube underwater arc-oxygen cutting electrodes outperform steel tubes in cutting thin and medium thick steel plates. The graphs further indicate that steel tube electrodes, regardless of their short life, are more efficient in cutting steel over ¾ inch in thickness. The latter electrode performs better with A. C. than the ceramic electrodes. However, the ceramic electrodes offer additional advantages which are not evident from the performance charts, namely:

(a) Better maneuverability in confined places owing to their 8 inch over-all length and long life.

(b) The light weight of the ceramic tube electrode. One hundred ceramic tubes weigh only 24 pounds packed for plane transport. This amount is sufficient to do the work of from 800 to 1000 steel tube electrodes weighing approximately 250 pounds.

Ceramic tube electrodes are also suitable for underwater cutting of stainless steel, copper and nickel base alloys and cast iron using the technique described above in connection with the steel tube electrodes. In addition, ceramic tubes can be used advantageously for cutting steel and the above listed metals in air. A recent development is the technique for removing defective austenitic weld metal from deep grooves in any position. The above development is of particular value for the removal of defective austenitic weld metal from deep groove joints in the

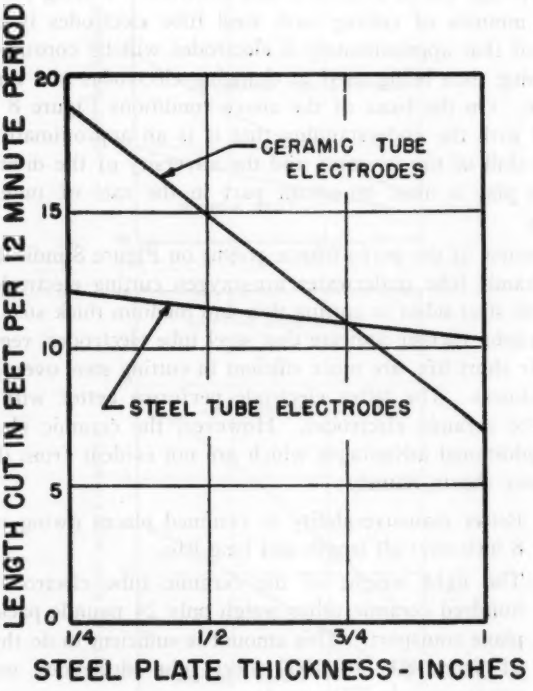


FIG. 8. COMPARISON OF CUTTING RATES FOR A TWELVE MINUTE CUTTING PERIOD.

flat position. The removal of defective austenitic weld metal cannot be readily effected by chipping for the reason that austenitic steel work-hardens. The often applied procedure of removing the defective austenitic weld metal by grinding, is a costly operation both in labor and materials. A fast and economical method for removing defective austenitic weld metal (developed by the New York Shipbuilding Corporation) employs the carbon arc as a source of heat and an air jet to blast out the molten metal. However, the application of this procedure for fixed flat joints calls for the use of minimum 600 amperes and further, as the procedure involves the simultaneous manipulation of the arc and an air jet, it requires a high degree of skill. The procedure for removing defective austenitic steel weld metal from fixed flat joints with ceramic tube electrodes is considerably slower than with the carbon arc method. However, it has the merit of requiring but 300 amperes at about 20 - 30 volts, oxygen at 3 p.s.i., of being extremely simple in operation, and of being controllable, that is, there is no danger of suddenly cutting deeper or wider than desired. The details of the technique for removing defective austenitic weld metal from joints fixed in any position using Ceramic tube electrodes are described in the following:

Equipment Required:

(a) Special type electrode holder, whose details appear on Figure 9.
(b) Oxygen regulator, secondary, low pressure 0 - 5 or 0 - 15 p.s.i. capacity.
(c) Water bucket placed on a board or other insulating material.
(d) Ceramic tube electrodes, metal sprayed, but without the insulating wrapper.

Technique:

The technique evolved in the use of the ceramic tube cutting electrode for removing austenitic weld metal is extremely simple, requiring no special skill or aptitude. It is not a melting or puddling in the sense metallic or carbon electrodes are applied to remove weld metal when the welded joints are positioned in the vertical or overhead positions; further, it is not similar to arc welding in that no arc is maintained by careful manipulation of

the electrode. The operation is simply rubbing the ceramic electrode back and forth over the area where the weld metal is to be removed. The operation is performed blockwise or progressively, removing only a portion of the weld metal in successively worked increments. The incremental length is also optional with the operator. The operation consists of rapid back and forth reciprocating strokes at a rate of 5 to 10 per second, dependent on the length of the strokes, with the electrode held perpendicular to the work, the tip of the electrode being in light contact with the work. If the operator choses he may accomplish the desired result by describing a circular pattern provided that he maintains the same speed of travel as in reciprocating. None of the above details of the technique are critical in that the operator is guided by the results obtained. The technique is correct when the weld metal melts forming balls or pellets which rapidly multiply with each stroke. After about one minute's continuous rubbing of an increment so many pellets are formed that they begin to interfere with the ease of operation; also, the tip of the ceramic electrode becomes very hot. Then the operator stops and places the electrode and holder in a bucket of water mounted on a board or equivalent material as regards electric insulation. As the operator resumes his work on another increment, the chipper removes the balls and pellets preferably by use of a pneumatic tool. The above-described routine of rubbing with the ceramic electrode and cleaning with a pneumatic tool is repeated, melting off layers of weld metal averaging 1/16 inch in thickness per operation until the desired volume of defective weld metal is removed. The appearance of a so-cleaned groove is illustrated in Figure 10. Arc time for removing one linear foot of austenitic weld metal from a one inch joint in the flat is 45 minutes.

Metallic Arc Cutting.

A procedure has been developed for emergencies such as the shortage of oxygen or the lack of tubular electrodes, where covered, mild steel welding electrodes are employed for cutting metals underwater. In fact this metal arc process is superior to the arc-oxygen process for cutting cast iron and the non-ferrous metals. Parting metals by Metal Arc Cutting is the same melting operation as given above in describing cutting of non-ferrous metals, cast iron or stainless steels with the arc-oxygen procedure,

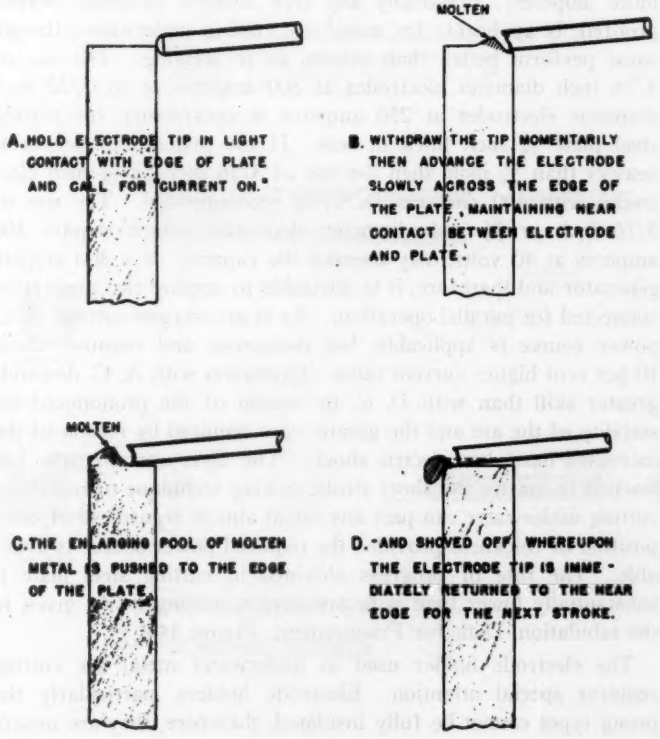

MOLTEN
A. HOLD ELECTRODE TIP IN LIGHT CONTACT WITH EDGE OF PLATE AND CALL FOR CURRENT ON.
B. WITHDRAW THE TIP MOMENTARILY THEN ADVANCE THE ELECTRODE SLOWLY ACROSS THE EDGE OF THE PLATE, MAINTAINING NEAR CONTACT BETWEEN ELECTRODE AND PLATE.
MOLTEN
C. THE ENLARGING POOL OF MOLTEN METAL IS PUSHED TO THE EDGE OF THE PLATE.
D. - AND SHOVED OFF WHEREUPON THE ELECTRODE TIP IS IMMEDIATELY RETURNED TO THE NEAR EDGE FOR THE NEXT STROKE.

FIG. 11. METALLIC ARC CUTTING OF THICK PLATE

except that the oxygen or air is not available for removing the molten metal; therefore, the diver-operator must compensate for it by manipulation as shown on Figure 11. To render the metal melted off by the arc sufficiently fluid to permit its removal by the simple short-stroke sawing manipulation shown on Figure 11, the current rate applied in metal arc cutting is from 250 to 400 or more amperes. Practically any type covered electrode, waterproofed, is applicable for metal arc cutting underwater, though some perform better than others, as in welding. The use of 3/16 inch diameter electrodes at 300 amperes or of 5/32 inch diameter electrodes at 250 amperes is satisfactory for cutting steel plate ¼ inch thick or less. If the material to be cut is heavier than ¼ inch, then the use of 3/16 inch or ¼ inch electrodes with 400 amperes D. C. is recommended. The use of 3/16 inch or ¼ inch diameter electrodes, which require 400 amperes at 40 volts, may overtax the capacity of a 300 ampere generator and therefore, it is advisable to employ two generators connected for parallel operation. As in arc-oxygen cutting, A. C. power source is applicable, but dangerous and requires about 10 per cent higher current rates. Operation with A. C. demands greater skill than with D. C. by reason of the pronounced instability of the arc and the greater care required by reason of the increased hazard to electric shock. The diver-operator who has learned to master the short stroke sawing technique of metal arc cutting underwater can part any metal almost regardless of composition or thickness provided the required power source is available. The rate of progress obtained in cutting steel plate is substantially lower than with arc-oxygen cutting. (As given in the tabulation, Data for Procurement, Figure 14).

The electrode holder used in underwater metal arc cutting requires special attention. Electrode holders, particularly the prong types cannot be fully insulated, therefore, they are unsafe and unsuitable for underwater use. The all plastic, shielded electrode holder designed for underwater metal arc cutting or welding, which is the approved model of the Navy Department, is shown on Figure 12. This holder is fully insulated and contains but one single hole for inserting the electrode so that the grip end of the electrode is safely within the holder. Details of construction of the above holder are shown on Figure 13.

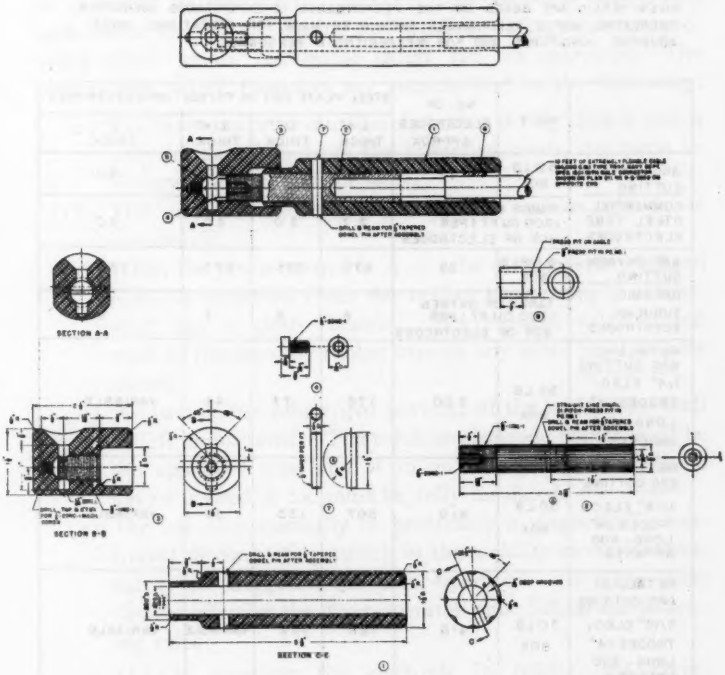


FIG 13

DATA FOR PROCUREMENT

TO ASSIST IN ESTIMATING THE QUANTITY OF MATERIALS FOR UNDERWATER CUTTING, DATA ARE OFFERED IN THE FOLLOWING TABULATION, THE DATA GIVEN HEREIN ARE BASED ON THE PERFORMANCE OF EXPERIENCED OPERATORS, THEREFORE, AMPLE ALLOWANCES SHOULD BE MADE FOR OPERATIONS UNDER ADVERSE CONDITIONS AND FOR INEXPERIENCED PERSONNEL.

	UNIT	NO. OF ELECTRODES APPROX.	STEEL PLATE CUT IN FT./BOX OF ELECTRODES			
			1/4" THICK	1/2" THICK	3/4" THICK	1" THICK
ARC-OXYGEN CUTTING	50 LB. BOX	167	240	170	170	160
COMMERCIAL STEEL TUBE ELECTRODES	TANKS OF OXYGEN (200 CU.FT.) PER BOX OF ELECTRODES		2.7	2.0	2.0	2.0
ARC-OXYGEN CUTTING	6 1/2 LB. BOX	25	475	375	275	175
CERAMIC TUBULAR ELECTRODES	TANKS OF OXYGEN (200 CU.FT.) PER BOX OF ELECTRODES		6	6	6	8
METALLIC ARC CUTTING 1/4" ELECTRODES-14" LONG-400 AMPERES	50 LB. BOX	220	176	77	44	VARIABLE
METALLIC ARC CUTTING 3/16" ELECTRODES-14" LONG-400 AMPERES	50 LB. BOX	410	307	135	58	VARIABLE
METALLIC ARC CUTTING 3/16" ELECTRODES-14" LONG-300 AMPERES	50 LB BOX	410	185	102	VARIABLE	VARIABLE

FIG. 14

PROCUREMENT.

As a guide for the procurement of supplies for underwater cutting a chart is provided on Figure 14.

SAFETY.

Electric underwater operations, using any of the above procedures may be extremely hazardous, especially in sea water which is in reality an electrolyte. Realizing the potential dangers of underwater electric arc cutting and welding, safe-guards are provided which assure reasonable safety for the operators. The outstanding safety measures are summarized in the following:

(a) The diver-operator must be clothed in diving clothes which fully insulate him from the grounded work, the torch or electrode holder, and the water.

(b) The use of rubber or rubberized canvas gloves is mandatory.

(c) When the power source is A. C., the diver-operator's head must be insulated from the helmet by wearing a woolen skull cap or cloth "beanie". The exhaust valve button must be insulated by rubber tape or any other fully reliable means.

(d) No part of the submerged portions of the lead cables shall be left uninsulated. The torch or electrode holder must be the approved type and if in an emergency a substitute device is used, it too must be fully insulated.

(e) The use of a manually or preferably a magnetically controlled disconnecting switch in the *welding circuit* is mandatory to safeguard the diver-operator. To make these devices effective the diver-operator must follow the following rules:

(1) On inserting the electrode in holder, the diver-operator is to locate the starting point, hold the electrode against the work and when fully poised and ready to cut, signal for "Current On".

(2) On having consumed the electrode the diver-operator shall not attempt to remove the stub until the request "Juice Off" has been confirmed by the tender, who does not confirm the request until the circuit has been broken by him, i.e., after the switch has been opened.

(3) The diver-operator shall be warned never to hold the torch or electrode holder in such manner that the electrode is pointing toward him, for that condition may entail about the same danger as holding a loaded pistol pointed toward his body.

(f) Tests showed that in all underwater metal arc operations hydrogen and CO gases are generated. Should these gases be entrapped within closed compartments they may constitute explosion or asphyxiation hazards or both. Therefore, it is mandatory that the compartment directly above zones of underwater arc-oxygen or metal arc operation be properly vented.

DEVELOPMENT OF CARBIDE HOBS FOR CUTTING MARINE PROPULSION GEARS.

By Alfred J. Kroog, Lt. Commander, U.S.N.R. and Richard W. Righter.*

One of the outstanding problems facing the Navy during the early days of the present war was the critical shortage of Marine Propulsion Gears. The outlook for meeting that shortage was dark particulary regarding equipment for cutting the larger size gears. A great proportion of these gears were to be cut on hobbing machines of a type and size that were limited in number with no relief in sight due to the length of time necessary to build large, high-precision machines. Prewar demands for large hobbing machines were comparatively small and the hobbing machine manufacturers could not cope with a problem as large in magnitude as that necessary to meet requirements for additional hobbers. Because of the resultant lack of reduction gears, it was necessary in many cases to use reciprocating engines and electric drives with their added weight and space.

Gear manufacturers extended themselves to meet production schedules and did a commendable job under conditions of material and labor shortages. Feeds and speeds were increased in many cases and in certain instances a single roughing cut and one finishing cut were used in place of the standard practice of two (2) roughing cuts and a final finish cut; and this was accomplished without sacrificing the degree of accuracy required for satisfactory gear performance.

Shortages of marine gears had existed before, during World War I, and in an effort to preclude any possibility of propulsion gears ever again becoming the controlling factor for the Navy's requirement of first class fighting ships, the Bureau of Ships established a program for investigating the possibilities of increasing the production of hobbed gears through use of hobs having cutting edges of cemented carbide.

The idea was not new, but previous attempts to use cemented carbide hobs had ended in very unsatisfactory results. An analy-

* Bureau of Ships, Navy Department.

sis of these results, however, was helpful in determining the techniques to be used in applying the new hobs. Of further aid, was the availability of improved types of cemented carbides that were developed specifically for steel cutting.

At the outset of the program, either a design of the hob similar to the one previously tried, Figure 1, or an entirely new design had to be decided upon. The carbide manufacturers and hob manufacturers advised against the first type because it was difficult to make. This hob was of standard high speed steel design except that pieces of cemented carbide were brazed to the radial face of the teeth to form the cutting edges. Due to the small size of the hob and lack of experience and equipment for grinding carbide, the hob was ground in a manner similar to that used for high speed steel hobs wherein small wheels were used for the "backing-off" operation. These wheels in this case were of diamond grit; however, their small size caused rapid wheel wear and the grinding developed into an exorbitant time and labor consuming operation. Brazing the individual pieces of carbide to the solid hob was reported as an intricate job in that it was difficult to locate the pieces and successive brazing was detrimental because the heat could not be localized due to the proximity of the teeth.

It was obvious that a larger hob was needed to facilitate manufacture and since increased size would permit an arbor hole of 2½ inches and the added weight would be an advantage from a carbide application standpoint it was decided that a design of hob showing in Figures 2 and 3 would be suitable. As indicated by Figure 2 the composite hob consists of a body with strips tipped with cemented carbide that are held in place by means of tapered wedges and set screws.

The hob is approximately 6 inches in diameter, 6 inches long, 2½ inches bore, 11 gash, 5 N.D.P. and 14½ degrees Nor. P.A. Because of its composite design it is possible to remove the cutting edge strips and replace them with various types of cutting-tool materials for test purposes.

The most significant change made when the Navy hobs were put to use was the direction of the hob rotation in relation to the feed. Previously, the conventional way of cutting was to rotate the hob against the feed wherein the chip was formed from 0 thickness to maximum thickness. This meant that the cutting

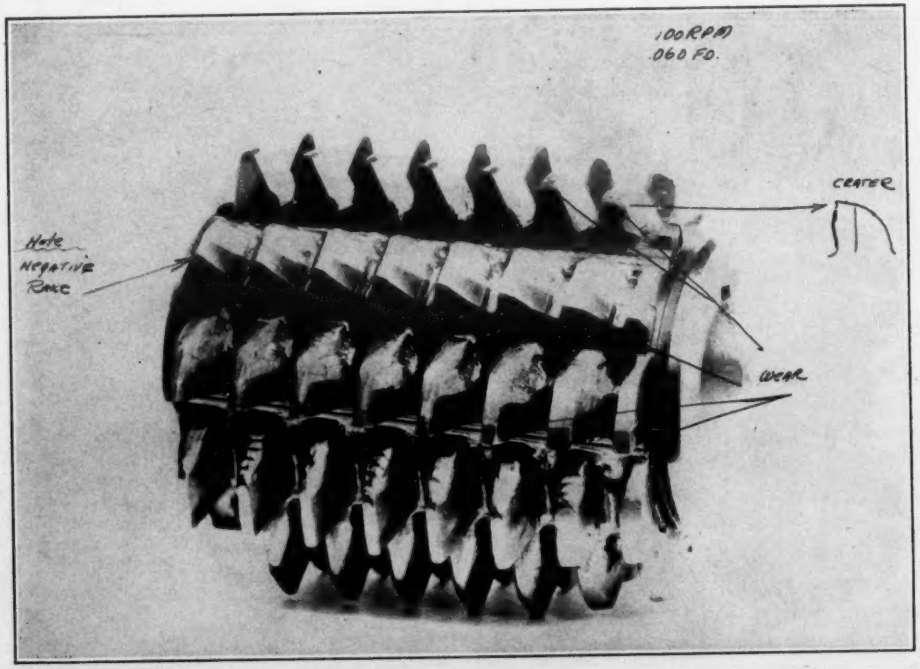


FIGURE 1.

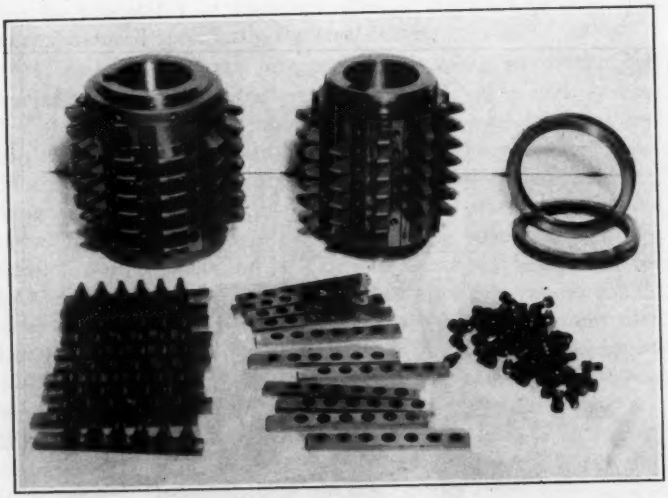


FIGURE 2.

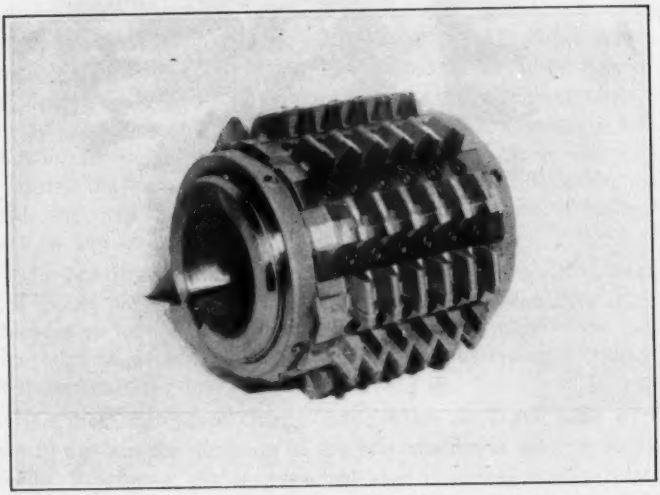


FIGURE 3.

FIGURE 4.

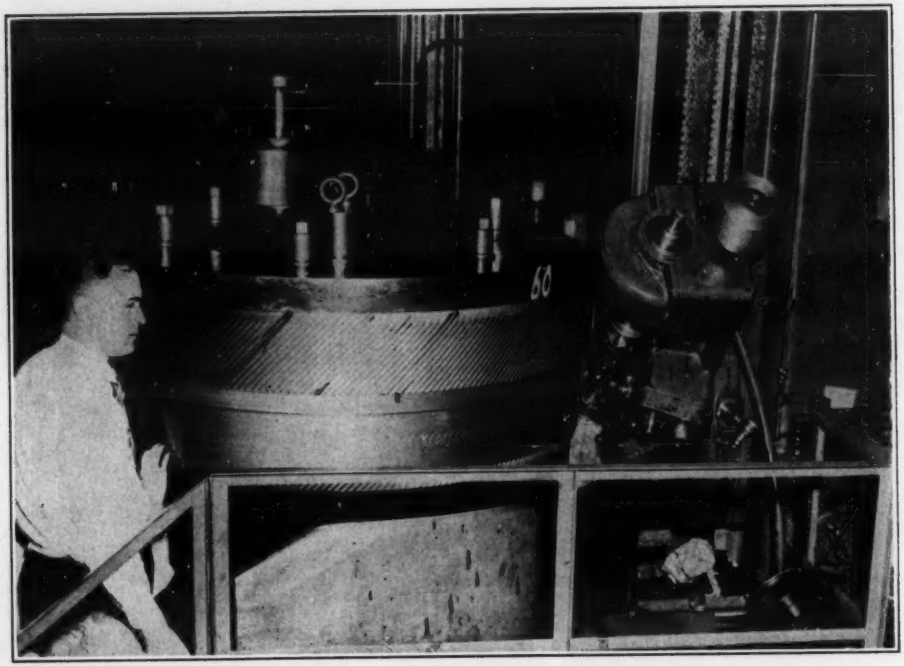


FIGURE 5.

edges for each chip taken rubbed the surface being cut until sufficient pressure was built up, caused by the advancement of the feed, to rupture the metal and start a chip. This rubbing dulled the cutting edge due to the abrasive action and resulted in premature failure. It was found that by employing a comparatively new technique developed for plain milling operations, that the hob cut freer and dulled less. Using this method, which will be referred to as "climb" cutting or "climb" hobbing herein, the rotation of the hob was in the same direction as the feed; therefore, chips were formed at the start by "biting" in a distance equal to the feed per tooth and tapering off to 0 thickness at the end. Such a technique can only be used where there is no back-lash in the feed screw or where a back-lash eliminator is used.

The selection of the proper grades of cemented carbide and the speeds and feeds at which to operate the hob were highly controversial. In general it was found that cemented carbide, although extremely hard in all forms, varied in hardness and toughness to suit the particular operation. For rough, heavy and interrupted cuts at moderate speeds, soft but strong grades are supplied whereas for light finishing cuts at high speeds a hard but comparably weak grade is used. Since little or no data was to be found regarding carbides for hobbing a general purpose grade was selected for the roughing cuts and a slightly harder grade for finishing. The grade for roughing had to be strong enough to stand interrupted cutting and yet hard enough to be wear resistant for several hours of constant operation. For finish cutting a hard wear resistant grade was necessary to withstand the abrasive action of a light cut and maintain size and sharpness to insure a good finished surface and an accurate tooth form and helix angle. From a cutting tool standpoint, hobbing is the most vicious of all metal removing operations in that the cutting edges are continuously subjected to varying depths of cuts and rubbing due to the generating action as the gear blank rotates past the hob. To add to the complexity of the situation it was found that the maximum speeds of standard hobbers were on the low side for optimum results with carbides.

The hobbing machine used for the first series of Navy sponsored carbide hob tests was a standard 72 inch Gould & Eberhardt hobber. This machine had a top speed of 100 Rpm. which gave the hob a peripheral speed of 157 feet per minute. A C-3 pinion

of approximately 21 inches diameter 95 inches overall length with an 18⅞ inch face width per helix, 5 pitch, 18 degrees 18 minutes 36 seconds helix angle and having a Brinell hardness of 240 was positioned for cutting in a split chuck firmly bolted to the worktable of the hobber. Feed per revolution of the gear blank was .040 inch and depth of cut was set for .395 inch. Climb hobbing was used. Grade K-4H cemented carbide was used for the first test run and cut the entire gear with good chip action and resulted in an excellent finish and an accurate helix. The only difficulty experienced was excess heating of the spindle bearings which were lubricated by grease cups and required constant attention at 100 Rpm. Dulling of the hob was confined to minor chipping on the lead tooth that had occurred at the start of the cut due to the fact that it was positioned in such a manner that the lead tooth was subjected to more than its share of the roughing cut. This was remedied by moving the hob and distributing the cutting load back from the entrance end.

After resharpening the hob by grinding the radial face with a 100 grit resinoid bonded wheel and removing the "feather" edges with a 200 grit diamond hone, a second gear of the same dimensions was rough cut and no chipping resulted.

This series of tests was completed by using a second hob of identical design but having cutting edges of solid high speed steel of the 18-4-2 variety, (18 per cent tungsten, 4 per cent chromium and 2 per cent vanadium). In rough cutting the other helix of the same pinion a speed of 50 Rpm., (78 feet per minute peripheral speed) in combination with a .040 inch feed was used. This speed was about 50 per cent greater than that used for standard high speed steel hobs, yet the hob did not dull extensively and cut freely with a good finish. The cut was made climb cutting and to prove that climb hobbing had certain advantages whether carbide or high speed steel hobs are used, the hob was resharpened and used to cut another helix in the conventional hobbing manner. The chip action was bad, finish scratchy and although the same speeds and feeds and depth of cut were used as when climb cutting, the machine labored considerable and the hob dulled noticeably more than on the first cut.

As a result of these first tests, it was obvious that changes would have to be made in the machine if best results were to be had. Primarily, more speed and rigidity and automatic lubrica-

tion were needed. Improvement was made by effecting the following modifications:

(a) 215 Rpm. at the spindle (formerly 100 Rpm.).
(b) Bronze bushings in place of the steel bushings in the spindle, intermediate and end arbor bearings.
(c) Oil supplied to the bearings on the swivel head, swivel head slide and drive shafts through a "Bijur" pressure oiling system.
(d) Combination overarm and steady-rest tying in the work support column with the stanchion.
(e) Flywheel added to the free end of hob spindle to increase stability and maintain uniform angular velocity.

Figure 4 shows the modified machine (upper left) and the standard machine (lower right).

In the second series of tests, using the newly modified machine, C-3 pinions with a special heat treatment that gave approximately 282 Brinell hardness were used. The first run was made with a grade K-3-H roughing hob, 133 Rpm. (209 feet per minute), .050 inch feed and .395 inch depth of cut. This grade of cemented carbide is slightly softer than the K-4H and was chosen to relieve the chipping action encountered in the first tests. Unfortunately, four of the teeth had been chipped in transit and further, the hob had inaccuracies both in the lead and tooth form. The chipped areas were lightly relieved with a diamond hone to allay chipping under use but no means were available to correct the lead errors. Although the hob was not within acceptable tolerances for roughing hobs it was decided to use it in hope that some measure of the cutting quality of this grade of carbide could be determined.

The inaccuracies of the hob showed up from the start of the cut in a slight ticking noise through the drive gear train. At first however, the cutting action was good but the hob dulled rapidly and the ticking noise developed into a steady pound in the machine that coincided in frequency to the hob revolutions. When the hob had cut 4½ inches, chatter marks began to show on one side of the gear teeth and after 7½ inches chatter marks were on both sides of the gear teeth. At 14½ inches several of the carbide teeth broke out of the hob due to constant abuse caused by unequal distribution of the cutting load. The dullness of the hob built up such a high side pressure that at the moment

the teeth broke, the hob arbor jammed into the spindle and stalled the machine. No serious damage resulted and the spindle was quickly adjusted and put in good operating condition.

To determine the possibilities of finish cutting with carbide hobs one helix of a C-3 pinion (282 Brinell hardness) was rough cut with a standard high speed steel hob so as to leave a .030 inch finishing cut for the carbide hob. (It was noted that the chip formation during the cutting and the condition of the high speed steel hob after cutting the complete helix was better than that usually found after cutting standard hardness pinions. This was evidently due to the better machinability characteristics of the harder material and the improved performance of the modified machine.) In further preparation for the finish cut with the carbide hob, the sulphur base oil used for coolant was replaced with a straight mineral base oil of lower viscosity to improve the cooling effect at the higher speeds and eliminate the damaging effect of the sulphur to the cemented carbide cutting edges.

For the finish cut, the harder grade K-4H was used and the machine set at 174 Rpm. (273 feet per minute), .090 inch feed and .030 inch depth of cut. The cutting action was very good, the finish was excellent and the helix angle checked well within the allowable tolerances. This cut took approximately 2 hours as against a normal 23 hours when using high speed steel hobs under standard cutting conditions.

After sharpening the K-4H hob by grinding .005 inch off the radial face the hob was set to take a roughing cut .400 inch deep. With a speed of 174 Rpm. (273 feet per minute) and .030 inch feed the cutting action was very good and after cutting approximately 7 inches it was decided to stop the cut and increase the spindle speed. The balance of the helix was cut at 224 Rpm. (351 feet per minute) at the same .030 inch feed. The finish of both portions of the helix appeared as good as that normally obtained by standard high speed steel finishing hobs. The carbide hob wore slightly more at the 224 Rpm. speed than it did at the 174 speed. Wear showed as a slight loss of clearance on the tooth profile cutting edges but there was no chipping.

This series of tests showed definitely that the modified machine will perform satisfactorily at the higher speeds using carbide hobs and also that definite advantages can be expected when the high speed steel hobs at standard speeds and feeds are used on such

machines. Other conclusions drawn from these tests were, (a) that a slight tapering of the entrance end of the hob would more evenly distribute the cutting load and discourage chipping, (b) the accuracy of the carbide hobs must be held within class (A) tolerances as established for standard high speed steel hobs, and (c) that carbide hobs can successfully cut gears of 300 Brinell hardness, and harder, at increased speeds and feeds with an excellent tooth finish.

The third series of tests were conducted on a 96 inch Gould & Eberhardt hobber that was modified as follows:

(a) Main center drive worm and gear in hob slide changing 11-27 ratio gears to 16-31 ratio.
(b) New center drive bevel gears in hob slide changing 27-22 ratio gears to 31-22 ratio.
(c) New helical gears at differential changing 72-54 ratio gears to 77-56 ratio.
(d) Special hob speed change gears of 53 and 29 teeth.
(e) Lubrication of hob slide drive shaft bearing and annular cutter drive bearing changed from grease to circulating oil.
(f) Flywheel mounted on hob spindle drive shaft in hob slide.

These changes permitted spindle speeds up to 200 Rpm. and resulted in quiet and smooth performance.

Figure 5 shows the modified machine.

A Carboloy Co. grade 883 R.H. cemented carbide tipped hob was used for the first run in this series, and was run at 200 Rpm. (314 feet per minute peripheral speed), .060 inch feed per rev. of gear blank, .022 inch depth of cut (finishing), direct drive (without differential), cutting a C-3, H.S., H.P. gear, 248 teeth and 9½ inch face per helix. This cut was completed in approximately 3¾ hours and records showed that a similar finishing cut with a high speed steel hob required 28 hours. The finish was very good due to the free cutting action of the hob. A slight dulling occurred on the teeth of the first convolution of the hob indicating the need for a slight taper to reduce the excessive load at the point of entry.

The next run was made with a Carboloy Co. grade 78-B, cemented carbide tipped hob, running at 200 Rpm. (314 feet per minute peripheral speed), .040 inch feed per revolution of gear blank, .410 inch depth of cut (roughing), differential drive, cut-

ting a C-3, H.S., H.P. gear, 248 teeth and 9½ inch face per helix. After cutting approximately 2 inches, the cutting action of the hob together with the surface produced indicated too rapid dulling and the cut was discontinued to permit examination. From the condition of the hob it appeared that the 78-B grade of carbide was too soft to withstand the abrasive action of the cut; however, it was decided that the hob should be reground with a longer and less steep taper and with a combination radial and axial rake to more evenly distribute the cutting load over a greater number of teeth.

For the next run, a Vascaloy-Ramet grade EM cemented carbide finishing hob was used to take a light finishing cut on the helix used in the first test run. This hob was one of two furnished with Vascaloy Ramets cemented carbide and both hobs showed cracked teeth under Zyglo test. (Although this condition was known to exist, it was necessary to take a finishing cut since it was part of these tests to determine the performance of various carbide hobs as furnished. Cracks develop from brazing strains and grinding checks and a hob will often perform entirely satisfactorily if the cracks happen to run perpendicular to the radial face but seldom are successful if cracks run parallel to the radial face.) The lead tooth came off after cutting 1½ inches so the hob was considered unsuitable for further test and removed. As a result of this experience, all hobs showing bad cracks will be eliminated from tests and records will be kept to assist in determining those grades that are susceptible to cracking.

Kennametal grade K-2S, L.H. cemented carbide tipped hob was used for the next test and was run at 200 Rpm. (314 feet per minute peripheral speed), .040 inch feed per revolution of gear blank, .410 inch depth of cut (roughing), differential drive, cutting a 40 inch gear, 196 teeth and 8¾ inch face per helix. This hob performed similar to the 78-B Carboloy hob in that it dulled rapidly and had to be stopped after cutting 1½ inches. It will be reground with a longer taper and given a negative radial rake to add support to the cutting edges.

The finishing hob used in the first test run was reground with a 2 degree negative radial and axial rake for roughing after the 78-B and K-2S hobs proved too soft. Grade 883 is a straight tungsten carbide intended for non-ferrous cutting; however, its physical properties, particularly its hardness, designed to resist

the abrasive action of segmental chip cutting, makes it suitable for hobbing operations. There was no way of grinding the end taper necessary for deep roughing cuts but it was decided to run the test due to the excellent showing it made on the first run. It cut 4½ inches of the 40 inch gear at 200 Rpm., .030 inch feed and .410 inch depth of cut. A good chip action and gear tooth finish resulted but the cut was stopped when lack of entrance taper began to abuse the lead tooth. All agreed that the hob could have finished the entire helix, but the hob had proved it could be used for roughing and it was decided that it should be reground properly with a taper for further test cuts.

The final two test runs of this series were made with a Kennametal grade K-4H, L.H. cemented carbide tipped hob. running at 200 Rpm., .060 inch feed, .020 inch depth of cut (finishing) and .030 inch feed with .410 inch depth of cut (roughing). This finishing hob was ground with a 2 degree negative radial and axial rake similar to the 883 hob and was used first to take a finishing cut over 4½ inch roughing cut made by the 883 hob above. The finish was very good and the hob showed no dulling so the feed was adjusted from .060 to .030 inch to continue roughing that portion of the helix left by the 883 hob. Although it roughed very well, the lack of taper had its effect and caused excessive dulling.

These tests proved the most fruitful to date in that finish cutting with carbide hobs has been definitely established and knowledge for designing roughing hobs is now believed complete. Since the grades of carbide selected for finishing were shown to be equally suitable for roughing, it is now planned to limit the grades to those having the physical properties of 883 and K-4H and limit design to one type for roughing and finishing. All hobs are to be reground in such a manner that further tests will incorporate all the desired features determined by the foregoing test run.

The chief reason for continuing the current program of carbide hobbing of marine propulsion gears, is to establish means for rapidly and accurately cutting gears up to 500 Brinell hardness. Plans are now being formulated to produce harder gears of smaller diameters by such methods as:

(a) Rough and finish hobbed and heat treated after cutting.
(b) Heat treated, rough cut, semi-finish cut and ground.

(c) Heat treated, rough cut, finish cut and shaved.
(d) Variations of these methods and possible use of lapping and super-finishing.

Facilities are being made available at the Naval Boiler and Turbine Laboratory to test complete gear sets and by co-ordinating the design, manufacture and testing of gears it is hoped that such efforts will result in lighter, more efficient and more dependable propulsion gear units.

A CHRONOLOGY IN NAVAL PETROLEUM TECHNOLOGY.

By W. C. Latrobe, Captain, U.S.N.*

Fuels and lubricants whether derived from natural petroleum or synthesized from gas, coal or shale, were products of vital importance to the military-naval services in World War II and they are most important in the plans for the future.

In time of peace industry thought generally only in terms of commercial application, for during peace the military services account for only a small part of the total production. This was further accentuated by the fact that military-naval equipment designed for war purposes requires high quality, harder to manufacture products that interfered with production destined for commercial applications and were less lucrative to market.

During the war the productive capacity of industry was taxed to the utmost and the military services sought greater and greater production from existing sources, new or unexploited sources, and substitute products of equal or better quality.

The military-naval services must therefore constantly assume the initiative in determining what are the products, and in what quantities and from what sources they can be made available, for the operation of both present and future designs of military-naval equipment and machinery. This has been and still is a mission of the Navy and it may be added that this is true not only for fuels and lubricants but also for *all* products which go into shipbuilding and shipmaintenance, both in peace and in war; and this mission has been made successful because of the Navy's close association with the technical staffs and research and development laboratories of industry.

Just prior to the war a program was initiated for the staffing of the various necessary petroleum groups in the Army and Navy with officers selected from the technical and administrative organizations in the petroleum industry, both to bring about coordination and coopeeration within government and industry, and provide joint thinking and joint action in the minimum time.

* Bureau of Ships.

This staffing program served the Allied Nations well during the war.

Now, the war is over and the Navy must plan for the future or post war military-naval era. These statements treat primarily with the problems that face the Bureau of Ships in carrying out its responsibilities in the design and maintenance and operations of naval ships and machinery. The Bureau of Supplies and Accounts, the Naval Petroleum and Oil Shale Reserves, the Army-Navy Petroleum Board and the various corps of the Army are parts of the whole picture.

The Bureau of Ships is a technical bureau. It and the other technical bureaus with their research and development laboratories form a unit or single group with similar aims, namely, the operation of all the present and future machines, engines and equipment that go on board ships or are used in support of ships or bases. This interest extends from the design room to the actual utilization in the fleet, for the kind of fuel or the kind of lubricant required for naval machinery in use goes hand in hand with the design of the machine.

For example improved metals and mechanical designs gave the Navy improved engines that would withstand higher temperatures. Then in order to employ these engines new lubricants had to be developed to withstand these higher temperatures. Likewise, when the hypoid gear with its high stress factors was designed, an extreme pressure lubricant had to be designed and specified for its lubrication. The transition from the slow-speed air injection diesel engine to the light weight high-speed solid injection engine involved a change in both fuel and lubricant.

Everyone has seen how the changing of the quality of motor gasoline has enabled the automotive engine designer to design and build better, more powerful and more economical automotive gasoline engines; or, perhaps another would say the engine designer confronted the petroleum technologist with a better engine requiring a new gasoline which the petroleum industry successfully met. Anyhow, the advent of 100 octane aviation gasoline has brought along with it the better aircraft engine performance and this and other super gasolines of World War II have made possible aircraft operations previously considered beyond achievement.

The same story is true of diesel engine development, for the

earlier engine was not limited particularly by fuel quality except that requiring freedom from impurities which clog fuel pumps and injectors. The experimental engine (German) in one of our submarines in 1932, brought out the need for a special diesel fuel; and so a new fuel with better ignition quality was prescribed.

A study of the work initiated by the Bureau of Ships will readily serve to indicate the scope of the Navy's interest in petroleum, or its synthesis, in all its phases and ramifications. The accomplishment of this work, needless to say, required at various stages of completion the assistance of industry (foreign and domestic), naval activities afloat and ashore in Navy Yards (Charleston, S. C., Boston, Pearl Harbor, Mare Island, and naval petroleum inspectors), ANPB, BuSandA, BuPers (personnel), Army Ordnance, BuAero, OQMG, PAW (Domestic), ODT, etc., which the attached "inspection chart" indicates.

The Navy must and does operate intimately with the petroleum industry; the Navy must seek and follow new sources for its materials; the Navy must take the initiative and with the assistance of the industry to obtain its materials both in quality and quantity. These facts are briefly illustrated here (chronologically).

Fuel oil has been defined broadly as any liquid petroleum product used for the generation of heat. It has been the by-product or "left-over" of refinery process and until recently it could not boast of being classed with highly-advertised gasolines and lubricating oils.

The first Fuel Oil Board, after two years test of an oil-fired boiler, reported favorably in 1904 upon fuel oil for use in Naval vessels. It was finally considered as the primary fuel about 1916. The first fuel oil was of variable quality depending upon the source of supply, but it was generally satisfactory in the earlier design of boilers and in boilers converted from coal burners to oil burners.

Fuel oil quality was not considered important enough to warrant much thought until about 1930, at which time Naval vessels became acutely aware of differences in fuel oil when some ships found fuel oils very difficult to handle and burn.

Fuel oil as a general topic has been and is being discussed in many phases. Generally it has been considered in problems of

petroleum reserves, storages, and diminishing availability with exhaustion of crude production.

Fuel oil should be viewed as vital material which should go hand in hand with advancing engineering designs of Naval installations as indicated by the changes in specifications for fuel oil and the *availability* of new quality materials procurable under present (or revised upward) specifications.

The story of bunker fuel oil from 1920 to 1936 has been one of establishing a Navy fuel oil as determined by costs, world-wide *procurability* and *availability*, and the design of equipment in use by the main forces afloat.

The ship in being (until the beginning of the Navy's renaissance) determined the mechanical limitations to be applied to specifications for bunker fuel oil, and the petroleum industry itself brought about the special specification for a Navy type of bunker fuel oil for Naval vessels. It would be better to say, that the petroleum industry brought upon itself special specifications for Navy grade fuel oil by reason of its trend in refinery practice to obtain greater yields in gasoline and heating oils.

When the production of crude was large and deep cracking not in general practice, the Navy enjoyed high quality or fluid fuel under "viscous" fuel specifications. Of course, during the ten-year period, 1920-30, the price of fuel oil varied. It was $2.00 a barrel during the early 20's when crude shortage threatened, and it was only $.10 a barrel when the Navy lifted top Mexican crude.

Until the early or middle 1930's, bunker fuel oil was classified as Bunker "A", "B", or "C", and each class was differentiated generally by viscosity. The bunker fuels were usually blended to produce a product with the desired fluidity without regard to compatability, or storage stability. Neither of these two important characteristics, stability or compatability, were of much importance until the Navy had to contend with mixtures of cracked products.

With the advent of more extensive and deeper cracking, the character of Navy fuel oil became extremely non-uniform as purchased under the existing broad specifications. It was particularly manifested during 1930 when the viscosity varied from 20 SSF to 120 SSF (at 122 degrees F.), and further, serious heater fouling and sludging in ships' bunkers were encountered. So, along with a general increase in viscosity the forces afloat

suddenly found seriously unsatisfactory characteristics to consider.

A thorough study of the fuel oil became imperative. Fuel oil investigation was begun at the Naval Research Laboratory at Anacostia, the Engineering Experiment Station at Annapolis and the Naval Boiler & Turbine Laboratory at Philadelphia. The Navy Cooperative Committee for Fuel Oil was established with technologists from the oil companies actively interested in cooperative research on this problem.

The research required a study of the military limitations of the Naval plant then afloat, since Naval equipment cannot be altered without tremendous cost to handle the more viscous fuels of the Bunker "C" varieties. These military limitations are set forth briefly:

(a) Boiler: Combatant ships are limited to boilers with small combustion space as compared to the large commercial boilers which permit burning the very viscous fuels.

(b) Burners: Naval vessels utilize the mechanical type, which type requires quality fuel oil. Steam, air and other types are required for burning the viscous fuels, but extra water for steam and the extra equipment required for these other types are prohibitive in naval vessels.

(c) Fuel lines: Combatant ships must limit the size of lines in order to reduce weight and space needed for armament and ammunition. Larger lines are required to handle adequately more viscous fuel oils.

(d) Pumps, Valves and Manifolds: Combatant ships are limited to size and type consistent with the distribution system; i.e., the same reason for smaller fuel oil lines.

(e) Preheaters: Combatant ships have preheaters for reducing the oil's viscosity in order to obtain proper atomization of 150 SSU at the burner. The preheaters are used for economical reasons; that is, they permit the use of cheap viscous fuel oils in time of peace. In time of war, a more fluid fuel oil, one not requiring heating, becomes most desirable. Even this attempt to utilize fairly viscous oils may result in casualties due to "coking" within the heaters or burner tips.

(f) Heating Coils: Steam coils are installed in fuel oil tanks in order to reduce the viscosity of the stored fuel, thus

facilitating pumping and transfer of the fuel oil to the fire rooms. This, again is an attempt to economize by the utilization of fairly viscous oils in time of peace. In time of war, the oil should not require preheating in tanks so that it may be transferred readily for damage control purposes.

(g) Fuel Oil Tanks: For ship stability, compartmentation, or damage control, and for placement of armament, combatant ships have small fuel oil tanks dispersed throughout the ships. A merchant ship usually has a few large oil compartments conveniently located adjacent to its fire-rooms with short suction lines leading to the fuel pumps, since short suction lines facilitate transfer of viscous fuels.

(h) Magazines: Combatant ships have magazines in which temperatures must be limited for ballistic stability of ammunition and safety of the ship. Fuel tanks are located perforce near magazines, and therefore, the temperature which may be necessary for pumping a viscous fuel oil may not be reached because of limiting magazine temperatures.

With military necessity for operating the fleet on the best fuel oil obtainable and at the same time obtaining the most procurable and the cheapest fuel oil possible within the limitations of peace time operations, the first stringent specification for Navy grade fuel oil was presented in March, 1936. Boiler design, acquisition of preheaters and bunker heating coils, and the design of pumps and fuel oil lines were based on the physical limitations of this reasonably cheap and readily procurable fuel oil.

A maximum viscosity limit of 65 SSF (at 122 degrees F.) was established in 1936. In addition to a viscosity limit which permitted pumpability when transferring oils from distant tanks under normal conditions, tests were established to assure the following quality in fuel oil:

(a) stability or freedom from pre-disposition toward fouling or clogging of preheaters and heating coils;

(b) freedom from formation of viscous tank sludges; and

(c) freedom from a product which formed excessive stack solids and fireside deposits.

Navy grade fuel oil since 1936 to 1941 was eminently satisfactory as the cheapest oil for use within the limitations of normal operation of peace time. The production of such a fuel oil was accomplished by the cooperation of the petroleum industry in its full realization of the Navy's particular needs.

1936-1937 marked intensified zeal towards the evaluation of fuel oil for the operation of the fleet 'in being' and the projected fleet in time of National Emergency. The fleet in being in 1937 had a satisfactory fuel oil, but what about the future? Navy fuel oil was a special product which was not normally found in commercial storages. By the changing refinery practices, as indicated by demands, the former cheap fuel oil which was available in large quantities was no longer readily procurable. "Bunker C" which was readily procurable was definitely unsatisfactory fuel oil for combatant ships. What was available as compared to several years ago? The available fuel oil appeared to be a distillate or heating oil, but it was not an especially cheap product. However, if the trend was towards the production of viscous fuels (industrial plant fuels) one had to consider the alternate, light or distillate type. So studies were begun on advantages and disadvantages of light oil and on present and future design of boilers and auxiliary equipment as well as a study of fuels suitable for long-time storage.

In 1936 the Navy Boiler Laboratory (now the Naval Boiler and Turbine Laboratory) began a program to obtain fuels from sources other than from the limited number of contractors supplying Navy fuel. Studies were begun on all types of crude oils from every available source in order to determine if, in time of emergency, they could be converted to suitable Navy fuel oils. The Director of the Navy Petroleum Reserves was asked informally what Elks Hills could produce in the way of quality and quantity, and how soon suitable fuel could be obtained to meet the requirements of the Pacific Fleet. Far-sightedness was required in planning for fuels for present and new design, and the fulfillment of petroleum requirements for war.

At the January 1937 meeting of the Navy Cooperative Committee, the Chairman (Naval Boiler Laboratory Officer representing the Bureau of Engineering) advised in confidence the quality required of fuel oil for National Emergency. This is the same quality requested and obtained for World War II.

During the period from 1936-37 the Navy Boiler Laboratory advised the Bureau of Engineering that much more adequate storages should be built and that boiler fuel oil suitable for long-time storage should be stored therein. The Chief of Naval Operations then established a Fuel Storage Board. The fuel board succeeded in obtaining limited approval for additional storages, and it accomplished the removal of viscous fuel oil in storage in Pearl Harbor and the substitution therefore of a better grade. The Navy had to look ahead in order to have fuels available for its fleet. Large storages were recommended for the West Coast and East Coast which, had they been constructed and filled, our problems in 1941 and 1942 might have been greatly simplified.

The year 1940 marked a radical change in fuels and lubricants. It was realized that peace-time fuels and lubricants were not satisfactory in time of war if better fuels and lubricants could be made available. In April 1940 the Navy (combined Bureau of Engineering and Bureau of Construction and Repair) indicated to the petroleum industry through its cooperative committee (established under the old Bureau of Engineering in 1932) the type of fuels and lubricants for National Emergency.

This letter indicated to the industry the trends in machinery design and indicated the types of fuels and lubricants necessary for the present and future designs.

It was indicated that the Navy must have—

(a) A much more fluid fuel than that currently obtainable, in order to obtain better pumpability (ease of handling), less stack solids, minimum pre-heating as well as obtain better control as regards stability and compatability.

(b) A better diesel fuel than that normally obtained on the West Coast in order to improve submarine engine performance.

(c) A new type of lubricating oil for diesel engines in order to prevent ring sticking and crankcase explosions, then occurring with currently supplied lubricating oils.

The supply situation indicated that at this time

(a) there was practically no Navy boiler fuel oil in storage in the United States.

(b) there was no high-cetane diesel fuel available on the West Coast for our submarines in the Pacific.

(c) there was no suitable lubricating oils for our submarine diesel engines any place in the world.

By December 1940 through the combined efforts of the Navy and the cooperative assistance of the technical members of the industry's cooperative committee with the Navy, Navy special fuel oil started to become available in increasing quantities.

By December 1940 the Navy, heeding the advice of members of the Navy Cooperative Committee, established specifications for high-cetane diesel fuel particularly to be applicable to the West Coast where there appeared to be none of this fuel oil in sight; however, the Shell Oil Company of California took the initiative and forthwith delivered to the submarines of the U. S. Navy its requirements for high-cetane diesel fuel.

By December 1940 through the test data of Caterpillar Tractor Company, General Motors Research Company, and the technical members of competing oil companies who had been testing the one and only completely new type (non-corrosive) lubricating oil developed by the Standard Oil Company of California, submarines of the Pacific had finally obtained the new type lubricating oil and were successfully operating to a degree heretofore believed unobtainable.

The Navy by means of its technical men within its laboratories, NRL, EES, NBTL, etc. and the technical men of the research development laboratories within the petroleum industry keeps informed of trends in machinery design and subsequent fuel and lubricant requirements. Industry, on the other hand, has kept the Navy and its laboratories advised of their own research and developments, while Navy has kept the industry advised of its probable requirements in the way of quantities of petroleum as well as quality. Assistance was given these oil companies in whatever way possible in order to obtain the quality and quantity of fuels and lubricants that the Navy would require.

In the early summer of 1940 turbine and gear manufacturers and certain of the oil companies indicated that rusting in turbine systems had been experienced ashore. Although no rusting problems had been indicated of any consequence in Naval vessels, steps were taken to evaluate turbine oils for rust inhibiting prop-

erties, particularly that turbine oil offered by the Wood River refinery of the Shell Oil Company.

In 1940-41 winter convoy duties in the North Atlantic in cold-rough weather brought about rusting conditions in turbine systems in destroyers. This rusting problem first came to light in early May 1941. By December 1941 the Wood River refinery of the Shell Oil Company was operating to capacity to provide this new turbine oil to all destroyers in the Atlantic where the salt water entrainment problem was most serious. During this same period technical members of the Marine Department of the Standard Oil Company of New Jersey, Socony-Vacuum and the Shell Oil Companies literally crawled through the engine spaces and sump tanks of destroyers in Navy Yards on the Atlantic Coast in order that they might assist Naval Personnel in determining the cause and cures for rusting turbine systems.

Up to 1927, lubricating oil for U. S. Navy use followed the commercial practice and was classified by the adjectives "light" to "Ultra heavy". This was confusing as the different adjectives did not always mean the same thing when applied by different producers. The Bureau evolved a symbol system of classifying oils which was gradually extended to other Federal activities until practically all lubricating oil used in the Federal service was obtained under Navy Department contract. During World War II, this symbol system has had Global use and has greatly simplified the procurement, storage and use of lubricating oils by the Allied Nations.

In the summer of 1941, an evaluation was made of the quantities of fuel oil in storage, or that which could be made available, on a global basis. This was made in order to determine the types of boilers, fuel lines, pumps and heaters for a group of vessels under design. It appeared at the time that heating oil (No. 2 furnace Grade) was available in millions of barrels in storage. Fortunately, these plans were held in abeyance, because this heating oil fuel became invaluable in our Aviation Gasoline program. This illustrates, all too well, how the Navy must be deeply and seriously concerned with the types of fuel oil and the availability of those types.

In the early fall of 1941, the Naval Technical Petroleum Service was established under the direction of the Bureau of Ships in order to protect the interests of the Government as well as the

purchaser in the procurement of petroleum products by the Bureau of Supplies and Accounts for Lend-Lease requirements. Technical petroleum officers were selected from industry and were given courses of instruction in the Engineering Experiment Station at Annapolis and in the Naval Boiler and Turbine Laboratory, Philadelphia. The responsibilities of these technical petroleum officers were, and are, great, since the contamination of a cargo of gasoline could immobilize planes and tanks; unstable bunker fuel oil could cause sludge and heater deposits which in turn would slow down or even cause the ship to stop; and diesel fuel contaminated with only a small amount of bunker fuel could be of untold seriousness to our submarines. This Naval Technical Petroleum Service was coordinated closely with the Army-Navy Petroleum Board, the Fuels and Lubricants Division of the Army Quartermaster Corps, Technical Petroleum Sections of the Army Air Corps, Navy Bureau of Aeronautics, etc., as indicated by the attached "coordination chart". Technical personnel were exchanged between the various petroleum groups within the Army and Navy in order to maintain a smoothly operating organization with 100 per cent teamwork.

In 1942 the Technical Petroleum Service was extended to foreign refineries shipping under Lend-Lease or direct Army-Navy contracts, by establishing Inspectors of Naval Material (petroleum) at Aruba, (Netherlands West Indies), Curacao (Netherlands West Indies), Trinidad (British West Indies,), Talara (Peru), Bahrein (Persian Gulf), Abadan (Iran), Cairo (Egypt), Haifa (Trans-Jordan). Naval Technical Petroleum Liaison Officers were established in London (England), Recife (Brazil). Petroleum Test Laboratories were established in Advanced Bases for "trouble shooting", in the many small diesel-driven vessels which were based there or in transit. With the rapid turnover of bulk petroleum in Naval storages, Technical Petroleum Groups as well as laboratory test equipment, were established under the Supply Officers in Command; or close liaison was established, in order to exercise quality control and make decisions on the spot without need for reference to the technical Bureaus or services involved. Technical petroleum officers were assigned to the Petroleum Divisions assisting in the invasion of Normandy and South France. All these naval technical petroleum officers were technologists selected from in-

dustry to carry out an assignment for the Military and Naval Services normally undertaken by industry during the peace; namely, to assure that all petroleum products in all theaters of operation were of the quality required (without contamination or inadvertent substitution) for the United Nations' tanks, planes and ships.

In order to exercise quality control over the products going to the Canadian Navy and to United States and Allied vessels obtaining petroleum products from Canadian sources, the Royal Canadian Navy established a Technical Petroleum Service with the Canadian petroleum officers who had received instructions in our Engineering Experiment Station and Naval Boiler and Turbine Laboratory. These petroleum officers, too, were picked from industry.

In 1943 an extensive study was begun on the possibility of producing crude oil from areas in Alaska, and the areas in the Netherlands East Indies in the hands of the enemies, and to obtain samples in order to analyze them for suitability in Naval vessels. A study of the production of oil from coal was reviewed, with the expectation of encouraging use of such oil by local civilians, in order that vital petroleum products and transportation might be diverted to strictly military requirements. Alaska needed oil, and the haul was long.

With the acquisition of suitably experienced personnel in 1944, serious studies were undertaken with regard to synthetic fuels. The work of the Bureau of Mines at Pittsburgh was studied. The Shale Oil Industry of Scotland and the products therefrom were thoroughly examined. Synthetic diesel fluids were obtained from industry and from a synthetic fuel plant in France. The result of these studies indicated that a high cetane diesel fuel from natural gas was a practical possibility; and the Secretary of the Interior was asked for advice with regard to establishing Natural Gas Reserves. At this time diesel fuels of suitable quantity were on short supply, and the addition of this synthetic liquid to low quality diesel fuels would (a) Increase the quality of diesel fuels considerably by adding 90 cetane liquids from natural gas and (b) Augment the total quantities of diesel fuel by the addition of this 90 cetane liquid.

The evaluation of Shale Oils, and the evaluation of oils from low temperature carbonization of coal were made in order to

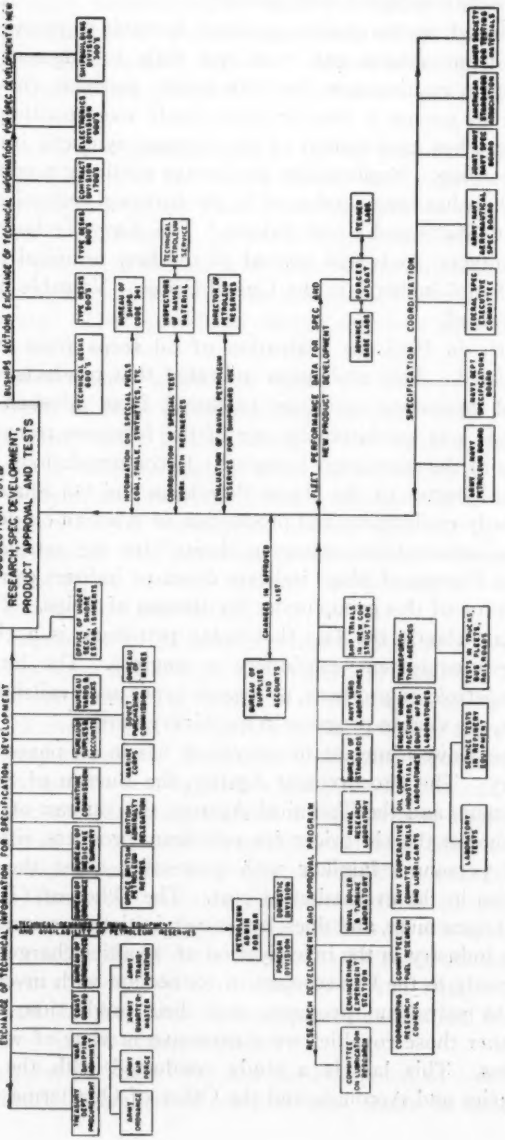
establish their utilization for Naval machinery. These evaluations were conducted with industry.

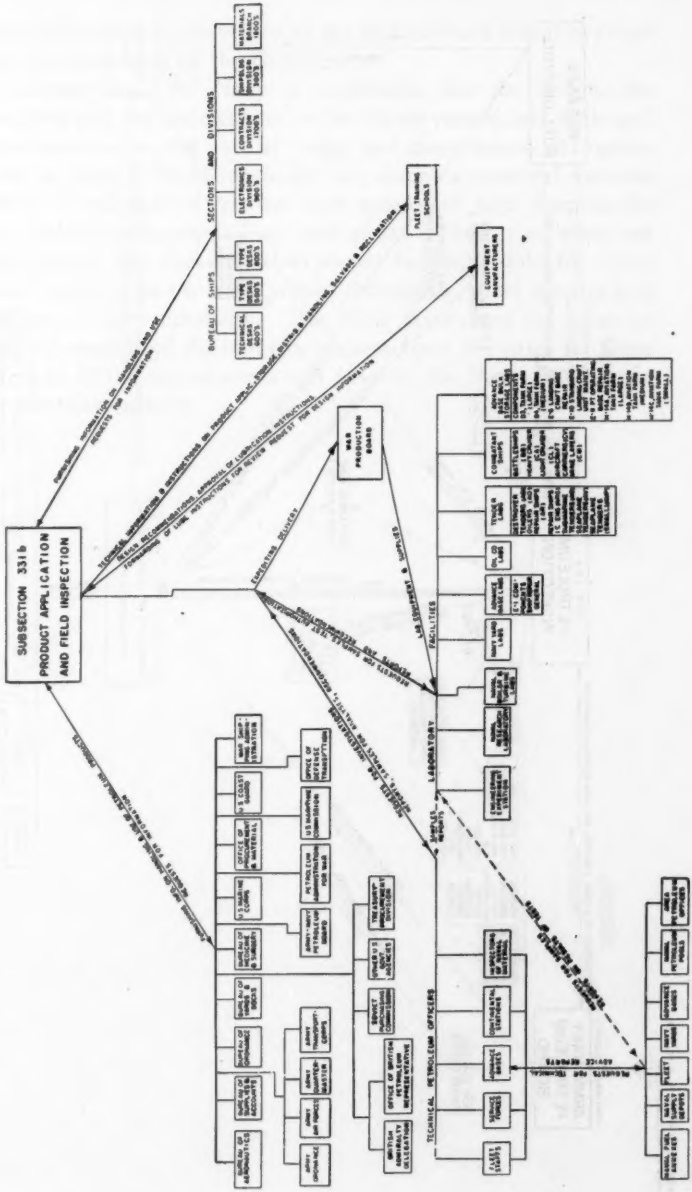
Although at this time it appeared desirable to process synthetic fuels from natural gas, coal and shale to augment our total petroleum requirements for high quality products, the Navy was loathe to pursue it since industry itself was unwilling to spend money when exploitation of the German synthetic industry was in the offing. Exploitation of German synthetic products of coal and shale has been conducted by the foremost technologists in the United States and Great Britain. The Navy Technical Mission on synthetic fuels had several of the best technical men in the "synthetic" industry in the United States. Valuable information was gained.

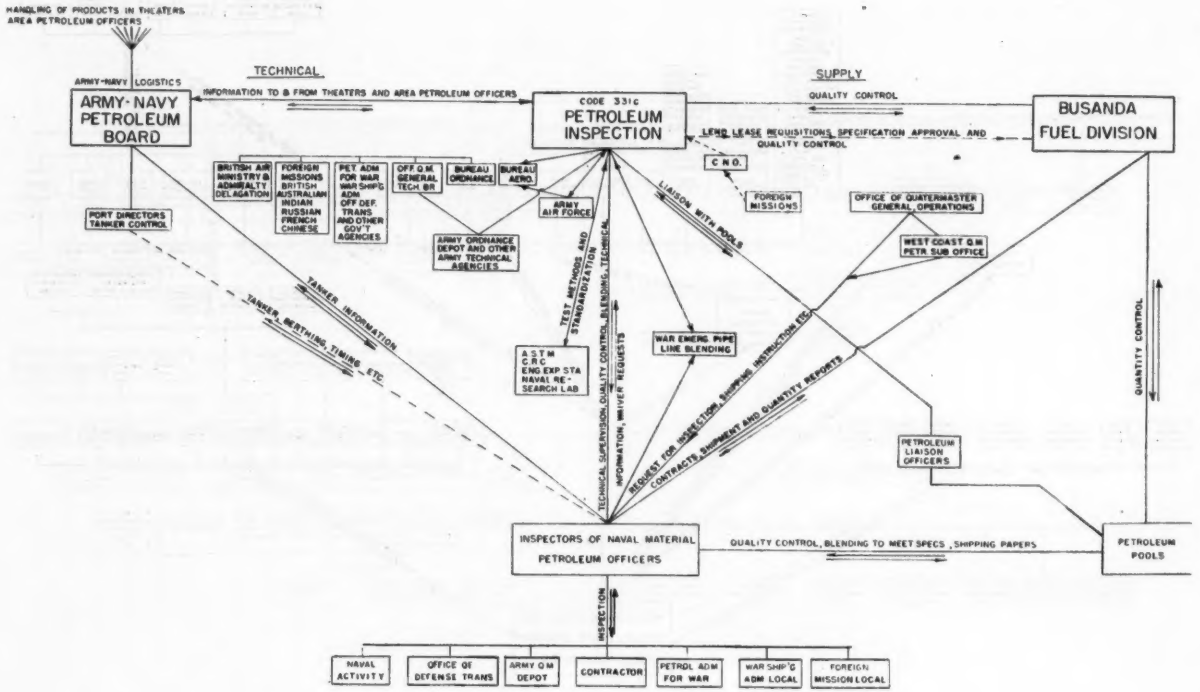
Early in 1945 the evaluation of oil seeps from Alaska was completed. This evaluation indicated that products valuable to Naval equipment could be produced from Alaskan oil. This analysis was conducted by one of the foremost research laboratories in the petroleum industry. Recommendations were made to the Director of the Naval Petroleum and Oil Shales Reserves for early exploration and production of Alaskan crudes.

The attached "coordination charts" for the petroleum groups in the Bureau of Ships indicate direct or indirect contacts in the operation of this group under the Bureau of Ships. These charts indicate clearly the fact that today petroleum is a vital part of modern equipment, machinery or engines. The limitations of these petroleum products, as regards types and availability of these types, are vital to progress in machinery design.

The Navy's interest in petroleum lies in all phases of the industry. The Procurement Agency, the Bureau of Supplies and Accounts, and the Technical Agency, the Bureau of Ships, look together at the bid prices for petroleum products, since the technical personnel familiar with processing assist the purchasing Bureau in the evaluation of cost. The Office of (Patents) and Inventions must, and does, by its own initiative, contact the petroleum industry in the investigation of royalties charged directly or indirectly to the Government in connection with inventions relating to petroleum products, and their production, to ascertain whether those royalties were excessive in view of war-time conditions. This last is a study conducted with the Bureau of Supplies and Accounts and the Office of Quartermaster General,


SUBSECTION 331.6
RESEARCH, SPEC DEVELOPMENT, PRODUCT APPROVAL AND TESTS
EXCHANGE OF TECHNICAL INFORMATION FOR SPEC DEVELOPMENT & NEW PRODUCTS
BUSDEPS SECTIONS
TECHNICAL DATA
600's
TYPE NEEDS
600's
TYPE NEEDS
600's
TYPE BOOKS
TYPES
CONTRACT DIVISION
TYPES
ELECTRONICS DIVISION
TYPES
SHIPBUILDING DIVISION
TYPES
INFORMATION ON SPECIAL OILS
COAL, FUELS, SYNTHETICS, ETC.
BUREAU OF SHIPS
CODE 341
COORDINATION OF SPECIAL TEST
WORK WITH REFINERIES
INSPECTORS OF NAVAL MATERIAL
TECHNICAL PETROLEUM SERVICE
EVALUATION OF NAVAL PETROLEUM RESERVES FOR SHIPBOARD USE
DIRECTOR OF NAVAL RESERVES
FLEET PERFORMANCE DATA FOR SPEC AND NEW PRODUCT DEVELOPMENT
ADVANCE BASE LABS
FORCES AFLOAT
TENDER LABS
SPECIFICATION COORDINATION
ARMY-NAVY AERONAUTICAL SPEC BOARD
JOINT ARMY NAVY SPEC BOARD
AMERICAN STANDARDS ASSOCIATION
LUBE GROUPS FOR TESTING MATERIALS
FEDERAL SPEC EXECUTIVE COMMITTEE
NAVY DEPT SPECIFICATIONS BOARD
ARMY - NAVY PETROLEUM BOARD
CHANGES IN APPROVED LIST
BUREAU OF SUPPLIES AND ACCOUNTS
NAVY TRIALS IN NEW CONSTRUCTION
TRANSPORTATION AGENCIES
TESTS IN TRUCKS, TRACTORS, RAIL CARS
RESEARCH DEVELOPMENT AND APPROVAL PROGRAM
PETROLEUM RESERVES FOR WAR
SYNTHETIC PROJECTS
NAVAL RESEARCH LABORATORY
BUREAU OF STANDARDS
NAVY YARD LABORATORIES
ENGINE MANUFACTURERS & ENGINE LABORATORIES
OIL COMPANY INDUSTRIAL LABORATORIES
NAVY COOPERATIVE FUELS AND LUBES RESEARCH
NAVAL BOILER & TURBINE LABORATORY
ENGINEERING EXPERIMENT STATION
COMMITTEE ON FUEL RESEARCH
COORDINATING RESEARCH COUNCIL
COMMITTEE ON LUBRICATION RESEARCH
LABORATORY TESTS
SERVICE TESTS IN NAVY EQUIPMENT
TECHNICAL DIVISION
BUREAU OF MINES
PETROLEUM ADMINISTRATION
SYNTHETIC LIQUID FUELS PROGRAM
PETROLEUM ADMINISTRATION FOR WAR
NAVAL PETROLEUM RESERVES
NAVAL OIL SHALE RESERVES
BUREAU OF MINES
GEOLOGICAL SURVEY
BUREAU OF STANDARDS
NAVAL RESEARCH LABORATORY
NAVAL BOILER & TURBINE LABORATORY
ENGINEERING EXPERIMENT STATION
COMMITTEE ON LUBRICATION RESEARCH
TECHNICAL DIVISION
BUREAU OF MINES
GEOLOGICAL SURVEY
BUREAU OF STANDARDS
NAVAL RESEARCH LABORATORY
NAVAL BOILER & TURBINE LABORATORY
ENGINEERING EXPERIMENT STATION
COMMITTEE ON LUBRICATION RESEARCH
TECHNICAL DIVISION
BUREAU OF MINES
GEOLOGICAL SURVEY
BUREAU OF STANDARDS
NAVAL RESEARCH LABORATORY
NAVAL BOILER & TURBINE LABORATORY
ENGINEERING EXPERIMENT STATION
COMMITTEE ON LUBRICATION RESEARCH


SUBSECTION 331b
PRODUCT APPLICATION AND FIELD INSPECTION
BUREAU OF SHIPS
SECTIONS AND DIVISIONS
TECHNICAL
TYPES
ELECTRONICS
CONTRACTS
DISTRIBUTION
WAR PRODUCTION BOARD
FLEET TRAINING SCHOOLS
EQUIPMENT MANUFACTURERS
LABORATORY
TECHNICAL PETROLEUM OFFICERS
FLEET
SHORE


HANDLING OF PRODUCTS IN THEATERS AREA PETROLEUM OFFICERS
ARMY-NAVY LOGISTICS
ARMY-NAVY PETROLEUM BOARD
TECHNICAL
INFORMATION TO & FROM THEATERS AND AREA PETROLEUM OFFICERS
CODE 331c
PETROLEUM INSPECTION
SUPPLY
QUALITY CONTROL
BUSANDA FUEL DIVISION
LEND LEASE REQUISITIONS, SPECIFICATION APPROVAL AND QUALITY CONTROL
C.N.O.
FOREIGN MISSIONS
OFFICE OF QUARTERMASTER GENERAL OPERATIONS
WEST COAST Q.M. PETR. SUB OFFICE
BRITISH AIR MINISTRY & ADMIRALTY DEL AGATION
FOREIGN MISSIONS BRITISH AUSTRALIAN INDIAN RUSSIAN FRENCH CHINESE
PET. ADM FOR WAR WAR SHIP'S ADM OFF DEF. TRANS AND OTHER GOV'T AGENCIES
OFF Q.M. GENERAL TECH. BR
BUREAU ORDNANCE
BUREAU AERO.
ARMY AIR FORCE
ARMY ORDNANCE DEPOT AND OTHER ARMY TECHNICAL AGENCIES
PORT DIRECTORS TANKER CONTROL
TANKER INFORMATION
TANKER, BERTHING, TIMING, ETC.
TEST METHODS AND STANDARDIZATION
TECHNICAL SUPERVISION, QUALITY CONTROL, BLENDING, TECHNICAL INFORMATION, WAIVER REQUESTS
LIAISON WITH POOLS
A.S.T.M. C.R.C. ENG. EXP. STA. NAVAL RESEARCH LAB
WAR EMERG. PIPE LINE BLENDING
REQUEST FOR INSPECTION, SHIPPING INSTRUCTION ETC.
CONTRACTS, SHIPMENT AND QUANTITY REPORTS
QUANTITY CONTROL
PETROLEUM LIAISON OFFICERS
INSPECTORS OF NAVAL MATERIAL PETROLEUM OFFICERS
QUALITY CONTROL, BLENDING TO MEET SPECS, SHIPPING PAPERS
PETROLEUM POOLS
INSPECTION
NAVAL ACTIVITY
OFFICE OF DEFENSE TRANS
ARMY Q.M. DEPOT
CONTRACTOR
PETROL. ADM FOR WAR
WAR SHIP'S ADM LOCAL
FOREIGN MISSION LOCAL

and indicates a responsibility of the Military and Naval Services for the protection of the Government.

Summarizing, the Navy is responsible for the design, the building and the maintenance of its Naval vessels, and fuels and lubricants are a vital part of design and maintenance and operation of ships. Petroleum today is a complex chemical material which is tailored to suit the high speed and high temperature of modern equipment ashore and afloat. Those that must use the product are the ones that should be responsible for those materials, and as has been proved thoroughly, users are the best judges of their suitability. The Navy determines the types of ships it needs, and the industry manufactures the parts for these ships to fill the requirements laid down by the Navy. Oil is one of those components.

FORMATION AND REMOVAL OF SLAG FROM SUPERHEATER TUBES OF MARINE BOILERS.

By Frederick R. Hock.

The fouling of external heating surfaces of naval boilers with deposits of fuel oil ash (slag, soot, cinder or clinker) has introduced a new maintenance problem. This is due in part to wartime operating conditions requiring long periods of cruising with short and infrequent availabilities for routine maintenance. The most extensive fouling of boiler heating surfaces has occurred on the external surfaces of convection type superheaters in all types of boilers, including superheat and non-superheat control, header, two drum "D", and three drum express types. Secondary to the slagging of superheater tubes is the fouling of carbon steel economizer surfaces. If deposits of ash and slag are permitted to accumulate without frequent periodic removal, the reliability and efficiency of steam power plants are adversely affected.

Figure 1 illustrates a slagged convection type superheater. It will be noted that the boiler has been opened for inspection and cleaning prior to complete blockage of the gas passages. The slag formation on the tube usually consists of rather uniform layer directly on the external tube surface with an irregular distribution of rather porous globular masses (resembling lava) adhering to the tube side layer. The slag varies in color from an earthy brown to soot black depending on the analysis and conditions to which it was subjected.

When the superheater tubes are slagged to an appreciable extent the superheated steam temperature and boiler efficiency is reduced, depending upon the extent of fouling. A typical example of the effect of superheater slagging is given by the operating data listed below:

	Builder's Trial	*Run with Fouled Superheater Tubes*
Steam Temp. — degrees F.....	825	730-740
Air pressure — inches of water...	16	28
Shaft speed — Rpm.	345.3	322

In addition, a large percentage of the gas flow is diverted around the bank of superheater tubes in lieu of flowing through it. This action causes premature failure of heat resistant materials in the zone of the superheater, i.e. superheater support plates; steam drum, water screen header and superheater header protection plates; access doors; soot blower elements and bearings; gas baffles. In the event that superheater header protection plates or superheater support plates burn out, the entire superheater must be retubed in order to replace these parts.

For the past three or four years all steam driven naval vessels have been fueled with Navy Special Grade fuel oil in accordance with Bureau of Ships Ad Interim Specification 7 0 1. The total ash content of this fuel oil is specified as 0.10 per cent (maximum). A large percentage of the fuel oils purchased to the above specification are well under the maximum ash content allowed. The sulphur content of the fuel oil is not limited by the above specification. In the fuels in question it usually varies between one to three per cent. Analyses of two fuel oil ash samples are given below in order to indicate the variety of elements entering the furnace with the oil:

Sources of Sample	*San Francisco District*	*Oil & Transport Co. Aruba, NWI Per cent by weight*	*Shell Oil Co., Calif.*
Si	1.7	0.5	3.2
Mg	0.35	trace	4.3
Pb	4.2	Nil	8.4
Fe	0.69	3.0	13.0
Al	0.54	10.0	3.0
Mo	0.064	....	0.17
V	1.05	63.9	13.0
Cu	0.13	....	2.1
Sn	0.15	....	....
Ni	0.47	5.5	5.3
Ca	0.45	2.8	2.8
Cr	0.15	....	0.15
Cl	.....	1.5	....
SO_4	.....	trace	....
Ash	.....	....	....
Na (by diff.)	*90.06	12.8	....

* Assumed to be K_2O and Na_2O

Although the ash content of the fuel oil is exceedingly low the total quantity of fuel oil fired is so great that an appreciable amount of ash is fired. A boiler burning 4000 pounds of oil per hour for 45 days (1080 hours) would have a maximum of 4320 pounds of ash entering the furnace with the fuel oil excluding any contamination with salt water. The steaming period necessary for a boiler to become seriously slagged varies, depending upon a number of incalculable factors. Present experience indicates a boiler may be heavily slagged with ash somewhere between 1400 and 6000 boiler steaming hours.

Analysis of slag samples removed from superheater tubes shows that the principal constituent of these deposits is a complex sulphate compound usually expressed as sodium sulphate or as the acid radical SO_3 with appreciable proportions of minor constituents. Slags obtained from boilers burning oils from Aruba also contain a considerable amount of vanadium. A spectrographic and chemical analysis of two slag deposits removed from two different superheaters is given below:

	Sample 1	*Sample 2*
	Per cent by weight	
SiO_3	....	1.8
P_2O_5	....	0.5
Fe_2O_3	4.6	5.1
V_2O_5	9.4	....
Na_2SO_4	51.7	....
$NaHSO_4$	19.3	....
Na_2O	....	10.2
SO_3	....	36.0
$CaSO_4$	2.9	....
CaO	....	1.8
$MgSO_4$	4.2	....
MgO	....	1.8
Al_2O_3,Cr_2O_3, and MnO	1.6	....
NiO	3.1	33.4
Cr_2O_3	....	3.6
C	0.8	....
Moisture	2.0	....
Ignition loss	....	0.1
Balance (undet)	....	5.7

NOTE: It is not assumed that the materials present are combined as shown but that these are the most likely combinations.

The slags exhibited a pronounced acid reaction and were quite soluble in hot water.

Since this problem is one of recent origin and the factors affecting slagging are so variable, it has not as yet been completely analysed. Although several explanations have been advanced describing the process by which superheater tubes become slagged, the writer considers that the problem is a result of chemical reactions which take place at temperatures between 600-1000 degrees F. This is the temperature level at which the external superheater tube surfaces in most marine boilers operate. The more important factors affecting superheater slagging in oil fired boilers are (1) tube temperature, (2) SO_2 conversion to SO_3, (3) ash and content of fuel oil, (4) high furnace temperature. It has been found that new boilers do not encounter slagging difficulties for a period of time, sometime referred to as the period of immunity. It is during this period that the external surfaces of the superheater tubes become oxidized forming iron oxide (Fe_2O_3) the necessary catalyst in the conversion of sulphur dioxide (SO_2) to sulphur trioxide (SO_3). (*) "It has been shown that firebrick, rusty mild steel (Fe_2O_3) and external scales containing sulphates removed from superheaters of two different boiler plants burning different coals exhibited catalytic properties which increased with temperature. Rusty mild steel was by far the most important catalyst in the temperature range investigated (up to 1200 degrees F). From the fuel oil ash analysis, it can be seen that the alkali-metal compounds enter the furnace with the fuel oil. It is believed that alkali-metal oxides evolve from the flames in high temperature furnaces and condense on the cooler boiler and superheater tube surfaces. When the alkali-metal oxides are surrounded by an atmosphere of SO_3 at the normal operating temperatures, alkali-metal sulphates are formed on the surface of the tube. During this period other low melting compounds such as vanadium oxide from the gases may also be deposited on the tube. (†) In addition it has been shown that mixtures of sodium or potassium sulphate and ferric oxide react with sulphur trioxide at 1000 degrees F to form sodium ferric trisulphate $Na_3Fe(SO_4)_3$ or potassium ferric trisulphate

* "High Dewpoint Temperature in Boiler Flue Gases", W. F. Harlow (Engineering, December 17, 1943).

† "External Corrosion of Furnace-Wall Tubes", R. C. Corey, B. J. Cross, and W. T. Reid, (Transactions of A.S.M.E. May 1945).

$K_3Fe(SO_4)_3$, respectively, at concentrations as low as 0.025 per cent by volume of SO_3. As the uniform layer of slag is building up the surface temperature increases to the point where it becomes slightly sticky causing other impurities in the gas to adhere. The mass appears to harden in a rather tightly bonded uniform scale until a layer approximately 1/16 inch is formed. The uniform layer stops when a surface temperature necessary to decompose these complex sulphate compounds is reached. At this temperature the surface appears to bubble and become irregular porous slag due to emission of SO_3 from the compounds. This action increases the surface temperature and the area of the sticky slag surfaces thereby trapping a high percentage of ash particles. The formation of sulphates and entrapping of other fuel oil ash particles continues until the gas passages of the superheater are completely filled with slag.

It can be readily seen that at the present time it is impractical to control the following factors causing this condition:

(1) Elimination of the sulphur in the fuel oil,
(2) Reduction of superheater tube temperatures,
(3) Elimination of ash in fuel oil,
(4) Elimination of oxide layer on tubes.

A recent addition to the Bureau of Ships Manual, Chapter 51, requires the cleaning of boiler, superheater, air heater and economizer tubes or elements as frequently as conditions permit. The maximum number of steaming hours between successive cleaning periods is limited to 1800-2000 hours.

Although an adequate number of soot blowers are installed in these boilers using superheated steam at 300 psi, the cleaning efficacy of these soot blowers is limited due to close pitch of tubes and the tenacious bond between the slag and superheater tubes. Due to the difficulty of removing slag accumulations on superheater tubes by hand, Navy Yard, Mare Island, and the Naval Boiler and Turbine Laboratory developed methods by which the slag can be removed by washing with hot water under pressure. At first it was anticipated that the water washing of boilers would have a deleterious effect on furnace linings and therefore in the early stages of this development the furnace brickwork and insulation was removed prior to washing. However, subsequent experience has shown that when proper precautions are exercised

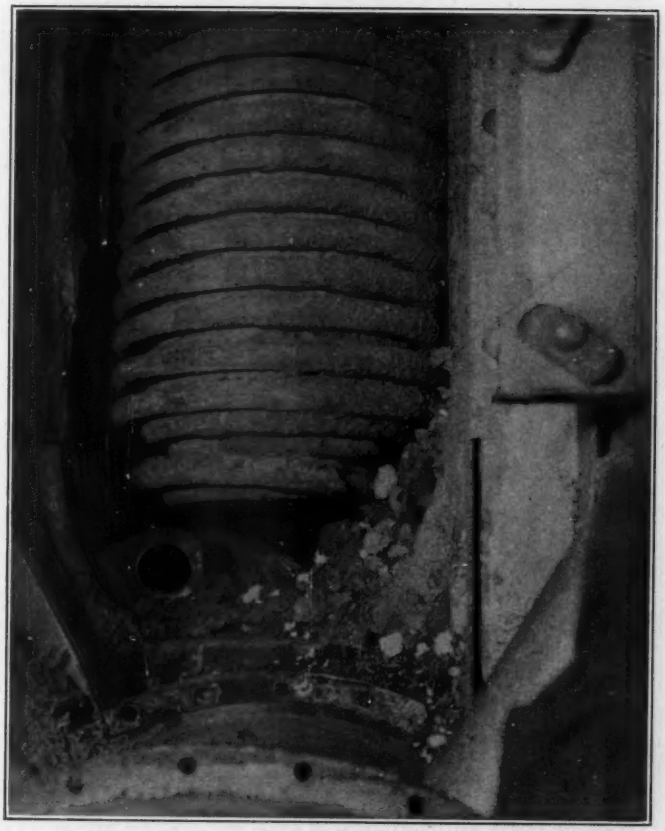


FIGURE 1.

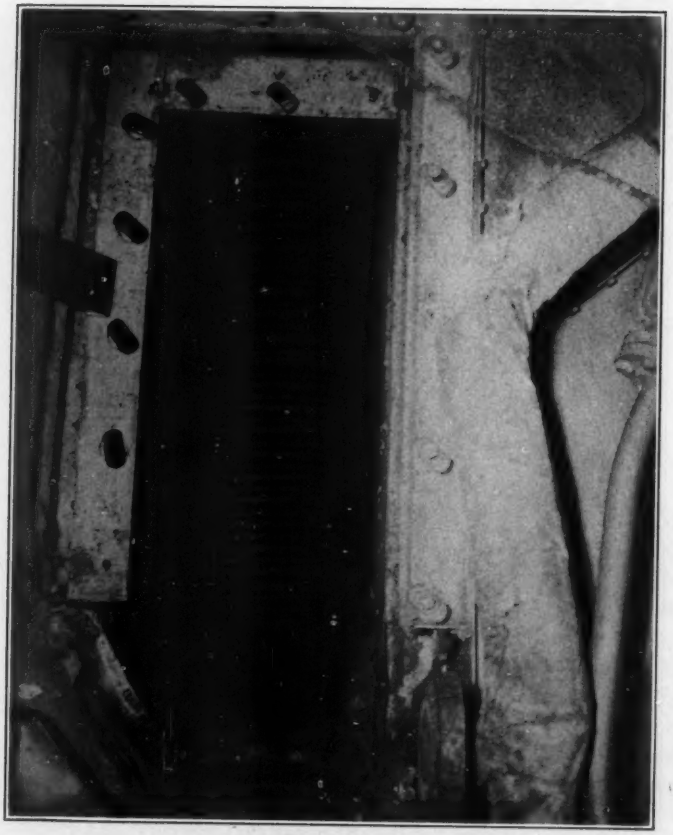


FIGURE 3.

the brickwork could be left intact during washing without any harmful effects to the furnace brickwork or insulation. The following methods of water washing is authorized by the Bureau of Ships.

(a) Remove all access doors and panels adjacent to the zone to be washed in order to lance all surfaces thoroughly.

(b) A source of hot fresh water at 150-200 degrees F is required. Usually the auxiliary or emergency feed pump is connected to the deaerating feed tank or to the pumping out connection on an idle boiler containing hot water. The pump is operated to maintain a discharge pressure of approximately 200 psi.

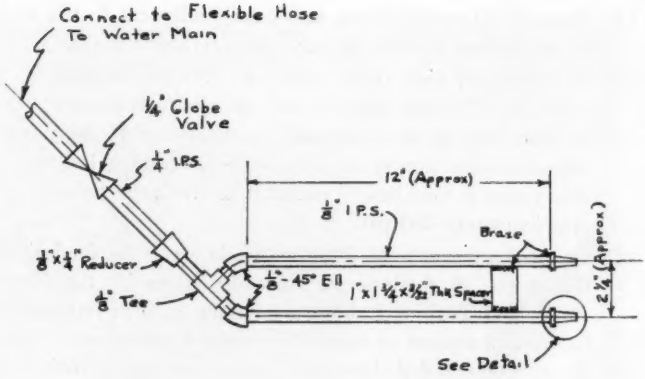
(c) Connect a steam hose fitted with a lance to the feed pump discharge. A dual nozzle lance developed by the Naval Boiler and Turbine Laboratory having ⅛ inch jets spaced to direct a stream of water between the tubes (see Figure 2) is recommended; however, a lance made of ¼ inch steel pipe flattened on the end will give fair results. Navy Yard, New York has washed some superheaters with good success by connecting the pump discharge to the soot blower piping, provided a soot blower is located near the top of the superheater. The soot blowers in this zone are then operated using hot water at 200-300 psi.

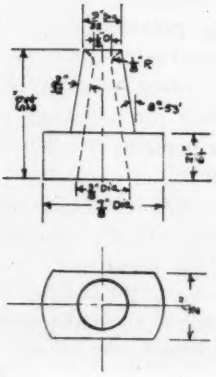
(d) Make provision for removing wash water from the furnace floor by pumping or allowing water to drain into the bilge by gravity.

(e) If an entire boiler is to be washed the economizer should be washed first. Wash from the top directing the stream through the gas passages. Next wash boiler tube bank directing the water toward the furnace. The superheater should be washed from the furnace and access doors at loop ends of superheater tubes.

(f) Secure water when lance is withdrawn for position changing—thus minimizing refractory surface wetting. The cleaning efficacy depends upon spraying small quantities of water in the proper places, not in soaking the tubes and adjacent surfaces.

(g) Continue washing of each section until the water draining from the boiler is clear. Actual washing of the boiler





Detail of
Nozzle

FIG. 2

should take from two to six hours depending upon the size of boiler and quantity of scale.

(h) Light off boiler as soon as possible after water has drained from floors and air casings. Replace access doors and panels. Light off one burner with the smallest size sprayer and fire intermittently for 15 minutes on and off for 5 hours using various burners one at a time. During this period superheater drains should be open to the bilge. Air dry unit for one hour after the five hour intermittent firing period, then light off unit and put it on the line in normal manner. If boiler is to be secured for a period exceeding 4 days after cleaning and drying out, the tubes should be sprayed with metal conditioning compound (Stock No. 52-C-3140) using about six gallons per boiler.

(i) When unit is first put in use after water washing, soot blowers should be operated frequently to remove remaining deposits.

Figure 3 is the same superheater as that shown in Figure 1, except the slag has been effectively removed by water washing.

NOTES.

INDEX TO NOTES.

A Single War Ministry.
—Journal of the Royal United Service Institution, May, 1945.

Vibration Problems in the Design of Marine Oil Engines.
—Transactions of the Institution of Engineers and Shipbuilders in Scotland, June, 1945.

Atomic Energy, a Survey of Its Nature and Possibilities.
—Shipbuilder and Marine Engine-Builder, September, 1945.

Power-Factor Improvement.
—General Electric Review, July, 1945.

Problems Connected with Reclamation of Worn Parts by the Metal-Spraying Process.
—Journal and Proceedings of the Institution of Mechanical Engineers, June, 1945.

Sharples Oil Purifying Processes.
—British Motor Ship, July, 1945.

Greases for the Bureau of Ships.
—Institute of Spokesman of the N. L. G. I., March, 1945.

A SINGLE WAR MINISTRY.

This article appeared in the Journal of the Royal United Service Institution—May 1945—as the Trench Gascoigne Prize Essay, 1944. While the essay as published bore no title, the above is used to describe its contents. The essay was written by Colonel J. H. Whalley-Kelly of the South Lancashire Regiment. It is an excellent discussion from the British viewpoint of the desirability of combining the Army, Navy, and Air Forces into a Single War Ministry. It is particularly timely because of the wide discussion of such a move in our own country at this time.

"The present war has emphasized the interdependence of the three Services on each other." This statement in the terms of reference requires no stressing and it follows, as a natural corollary, that unless unity of purpose and effort is achieved, and maintained, success in total war cannot be ensured. Further, without this essential unity, in time of peace, the armed forces cannot be adequately trained and equipped to meet the conditions of modern total war. In any future war in which the British Empire is involved the opening phases may well prove decisive. We cannot expect on the next occasion, should it arise, to set our house in order after the die is cast and therefore we must ensure that we can act effectively and with speed the moment hostilities open.

The conduct of modern total war is very complicated and embraces all the resources of the national life and economy. This fact, which had long been recognized by thinkers and writers, was emphasized in the War of 1914-18 and, within the limits imposed by public apathy, financial stringency and the policy of unilateral disarmament, the three Services did their best to profit by its lessons. The whole machinery of Empire defense was overhauled, an Imperial Defense College was established which was attended by selected officers from all three Services as well as by senior representatives of the Civil Departments, and great attention, in thought if not in deed, was given to combined training and combined action in war. It cannot be said, however, that real unity of effort and purpose was achieved, as each Service continued to develop along distinct and independent lines. Despite the interchange of ideas among the comparatively few officers who composed the higher levels, there was much divergence of thought and action and a good deal of political rivalry when it came to the presentation of the annual Estimates, sparse though they were.

Out of the welter of the last war there emerged one new factor of paramount importance in the waging of war, namely air power. Rightly or wrongly, the R.A.F. was brought into being as a separate Service in 1918 and thereafter survived every attempt to abolish it as such. Unfortunately, from the point of view of practical experience, that war was won while the air arm, as we know it to-day, was still in its infancy. Its full implications, and their influence on war in the future as the design and performance of aircraft improved, were left largely as matters for theory and conjecture. Enthusiasts like the Italian General Douhet, and many other writers, maintained that future wars could be won by the air arm alone if used to bomb the civil population into submission. At sea, the demise of the battleship and all other large surface craft was prophesied, while on land it was maintained that air attack on the civil population would prove decisive before the main opposing armies could come to grips. Up to date, the march of events has falsified all these extreme theories, but the fact remains that the air arm with its versatility and ability to strike swiftly has now amply proved its paramount influence on the conduct of all operations by land or by sea.

It is obvious that if it was difficult in the past to co-ordinate the activities of the Army and the Navy working in two elements it is still more difficult to achieve unity of purpose and effort when a third Service is

superimposed working in a third element, especially when the support of this new Service is essential to the two older.

At this point it is therefore relevant to examine briefly the machinery set up by Germany to conduct the long planned war of aggression on which she embarked in September, 1939. By tradition and necessity the German Army is the State. Nevertheless, a close study of the lessons of World War No. 1 convinced the Germans that in preparing for, and waging, World War No. 2 an integration of all three Services was essential, more especially in view of the growing power, influence and versatility of the air weapon. Therefore, the three Services in all planning, preparation and execution are considered as *one* and are referred to as the *Wehrmacht*, or armed forces. The action of the *Wehrmacht* is controlled and directed by an organization known as the *Oberkommando Wehrmacht* (O.K.W.), although each Service still retains its own Ministry to deal with the execution of operations (as directed by O.K.W.), training and internal supplies and administration. The German Army remained, and still remains, the predominant partner, but a close integration was achieved, especially between the Army and the German Air Force, in training, planning and operational execution. For example, it is accepted that, on the higher levels, a G.A.F. officer may command an Army group, and vice versa, which function both by training and experience these officers are qualified to exercise.

A good illustration of this system is provided by the campaign in the Mediterranean in 1942 when Kesselring—a G.A.F. officer, commanded the German forces in Italy and the Balkans, while Rommel—an Army officer, commanded in North Africa. Kesselring was charged with the responsibility of keeping Rommel supplied with men and material which necessitated safeguarding the air/sea communications across the Mediterranean. It is now fairly well established that the relations between Kesselring and Rommel were not harmonious, the rift apparently occurring over the vexed question of priorities in the use of the available air power in the spheres of both combat and supply. From this, it would appear that not even the Germans have evolved a system which eliminates the clash of personalities and the human factor, and it is unlikely that any one ever will. Nevertheless, it is suggested that the German system is calculated to maintain in peace, as in war, a higher degree of unity of purpose and effort than our own, but whether we could adopt it in its entirety or even in a modified form is another question. Dictatorships can adopt methods impossible in a democracy.

The terms of reference ask how the lessons learned up to date can best be applied so that unity of purpose and effort can be maintained after the War. Although this phrasing implies that the required unity has been achieved, and maintained, *during* the War, it is arguable that despite the admitted interdependence of the three Services there is still divergence of both purpose and effort: a Trinity without the Unity. In fact, it is asserted by many who are well qualified to judge that one of the major lessons of the War is that the organization of the three Services and the machinery for their control and direction are out of date and incapable of begetting that complete unity in their combined action which their very interdependence demands.

It would appear, therefore, that any discussion regarding the application to the post-war period of lessons learned up-to-date would be profitless until such lessons as are applicable are clarified and examined. This the writer proposes to attempt as an essential step in arriving at conclusions and making recommendations.

Owing to the nearness of events and the veil of secrecy it is difficult to pronounce judgment and deduce lessons from the conduct of the War up to date. Perhaps only the historian with a full knowledge of *all* the facts

can give the final verdict. Nevertheless, it seems quite clear that just as the War has emphasized the interdependence of the three Services, it has also demonstrated the weakness of the present system for control and direction which relies on compromises, improvisations, goodwill and endless committees to achieve the necessary unity of effort.

It is all very well to argue that we are winning the War, and that the system suits our national psychology and "team" spirit and that therefore it works. In war, it has to be *made* to work and it does, because there is a positive incentive in that the enemy constantly presents problems which must be solved with speed and determination. Even so, how many opportunities have been lost and resources wasted in the present struggle through failure to reach a speedy decision not only in the operational sphere but also in design, production and the allotment of priorities. Further, with three co-equal Services each with its own Cabinet Minister, are not divided counsels likely to prevail as to the choice of objectives or the selection of the decisive time and place to strike? A classic example is perhaps that of the stragetic bombing of Germany's industry and war potential, essentially long-term in its effect, versus the provision of the immediate air support required by both the Army and the Navy in their fight against the armed forces of the enemy on land and at sea. Unfortunately, aircraft have to be designed and crews trained for specific and, in many cases, highly specialized roles and therefore, while the heavy bomber force required for strategic bombing can rarely pull its full weight in direct and close support either of the Army or of the Navy, the aircraft and crews of the Tactical Air Force cannot carry out the functions of the former. Admittedly, the ideal is to carry out strategic bombing as well as providing 100 per cent close support for the Army and the Navy, but if both cannot be catered for which should have priority?

The writer does not propose to enter into the pros and cons of that argument as it is outside the scope of this essay, but it is significant that it took three years of war to give birth to the Tactical Air Force and for the provision of suitable Fleet Air Army aircraft, and the delay cannot be attributed solely to "time lag" in manufacture and the training of crews. Although the object of all three Services was the same, *i.e.*, to win the war, each had its own idea as to how to do it, the net result being a multiplicity of objectives with consequent lack of concentration of balanced forces plus a continual scramble for priorities superimposed.

The finale of the Libyan campaigns, the successful outcome of the descent on North Africa followed by the liberation of France and Belgium prove that a large measure of unity of effort and not only of purpose has now been achieved. In other words, the machinery has been made to work and a close integration of the three Services has been built up.

It must not be forgotten, however, that close and effective co-operation between the Services, either in planning or in actual battle, depends primarily on the personalities at all levels who are concerned. The human factor is still all-important even in this age of applied science and mechanics, and it will always be so. The stress of war and the fight for national survival brings to the top men who are prepared to sink their individual interests, views and differences, to promote the good of the common cause. Further, in the hard school of battle, experience, as opposed to the speculation and theory of peace exercises, is quickly acquired at all levels, so that there is at present a body of men of all three Services who fully realize the vital necessity of close and effective co-operation, and who are imbued with what may be termed an inter-Service outlook and attitude of mind. Unfortunately, these men cannot live for ever, nor will the edifice of inter-Service co-operation which has been built up during the War survive unless the foundations which have been so laboriously laid are consolidated and the edifice itself endowed

with the services of men who have been specially educated and trained to follow in the footsteps of the pioneer builders.

If the above reasoning be accepted, it follows that Cadets for Commissions should receive their education in military matters—using the word military in its widest sense—at the same establishment, irrespective of the Service they intend to enter. It is therefore suggested that an Imperial Defense University be instituted at which candidates for Commissions would receive at least two years training, entry to be governed by a combination of examination and interview, with a quota for men selected from the ranks of the Royal Navy, Army and Royal Air Force and Cadets from the Dominions.

The syllabus for the first part of the course would include the teaching of the characteristics, tactics and organization of the Service in which individuals had elected to enter (*i.e.*, Army, Navy and Air Wings) plus general military and Empire history and attachments to units. The second part of the course would be devoted to discussion, combined exercises and the general technique of inter-Service co-operation and the part played by the Civil departments of State in total war. Further details of the proposed Defense University are irrelevant to this discussion, but it is clear that unless a common basic education is given to intending candidates the object of maintaining unity of purpose after the War cannot be achieved. The inter-Service outlook and attitude of mind *must* be inculcated into all applicants for Commissions at their most impressionable age and prior to the specialized training required to make them efficient officers in the Service they eventually join. If entry to the Defense University could be extended to include a proportion of those intended for the Civil, Consular and Diplomatic Services it would be all to the good.

It will no doubt be contended that the whole proposal is too revolutionary, but the writer considers that a proper basic military education is a primary and essential step in maintaining unity of purpose and effort, as effective co-operation goes deeper than the setting up of committees of high level officers which, without the positive incentive of urgent problems, tend to let vested interests and a parochial outlook color their views and conclusions.

The next lesson learned from bitter experience in the war years is the urgent necessity for a common staff procedure. Total war is very complicated and at every stage of operations, whether strategical or tactical, the making of sound decisions and subsequent execution depend on intricate staff work. Under modern conditions no commander can be expected to give correct decisions, or implement them, without an efficient and highly trained staff. These days every project involves at least two of the Services and therefore all commanders and staff officers should be trained in combined operations and thoroughly understand the characteristics, powers and limitations of all three.

In this war, a staff efficient to deal with combined operations has been laboriously built up, largely by trial and error. Curiously enough many of the officers who graduated before the War at the Imperial Defense College, which was designed to give higher training in combined operations, Empire defense and the principles of total war, appear to have fallen by the wayside, but in any case the number of graduates was all to few.

The necessity for an efficient staff trained in combined operations, in a procedure common to all Services and imbued with a common doctrine is bound up with another outstanding lesson of the War, namely the necessity for speed: speed, not only in terms of mobility, but speed also in decision, planning and the assault of balanced forces at the selected time and place. Given that the making of a correct decision under the conditions of total war depends largely on the factual data presented by the combined staffs, it is equally true that it cannot be executed effectively without the highest

standard of staff work. Unless there is a common procedure and a common doctrine, delay and friction at every stage will occur, and the opportunity, so often fleeting, to deal a decisive blow or counter a threat by the enemy, may be lost. As Napoleon is alleged to have said, "Ground lost can be regained, but *time* never," and every event in this, as in every war, emphasizes the soundness of this assertion and the vital influence of time. In peace, unless there is a common staff procedure and doctrine, time will inevitably be lost or wasted in training on the wrong lines, producing the wrong equipment or in not keeping abreast of development and scientific invention.

It seems unnecessary to labor the point and the writer concludes that in order to maintain the unity of purpose and effort which has grown up during the War it is essential to institute a Combined Staff College at which selected officers of all three Services would be trained. The existing Staff Colleges could be retained for the training of junior staff officers, but their curriculums should be drawn up in the light of the interdependence of the three Services, and the best officers on each course should be earmarked for attendance later on at the Combined Staff College. Obviously, mere training at such an institution is not sufficient; the officers who graduate must be employed in appointments where they can add practical experience to their theoretical and academic knowledge. As regards this aspect the hope may be added in parenthesis that the peacetime training of the post-war years will include frequent and realistic combined exercises with troops as a matter of course and not of rarity as heretofore.

The question of priorities has already been mentioned. Priorities range from those in the purely operational sphere to the allotment of manpower as between industry and the individual Services, and again from the assignment of raw materials to the allocation of shipping. Their correct assessment is a concomitant of success in every phase and every activity of total war.

In peace, when financial stringency may intervene and problems of defense tend to become academic owing to the absence of the stimulus and urgency of war, it is more than ever necessary to ensure that the bidding for priorities does not become a source of inter-Service rivalry and political competition. Under the heading of priorities, so far as peace time is concerned, the voting of the annual Service credits looms large.

As this question of finance is all important if defense propositions in peace are to be adequate and united in their singleness of purpose and effort, it is appropriate at this stage to suggest that the three Service Ministries be combined into one Ministry of War—not to be confused with the present War Office. It is a favorite pastime of writers in the popular Press, and others, to recommend the fusion of the Navy, Army and Air Force into one Service to be known as the King's Service. The writer, although not conservative, suggests nothing so revolutionary: that some such fusion may occur in the future is not beyond the bounds of possibility, but it must come about by means of evolution rather than by a drastic re-organization immediately after the present war.

Meantime, while we have the Parliamentary form of Government, it is obvious that the maintenance of the armed forces in peace time in an efficient state of readiness for war depends largely on the state of public opinion. It is perhaps fair to say that the Navy is traditionally popular, the Air Force is spectacular and therefore appeals to the imagination, while the Army always appears to be treated as a sort of Cinderella. Therefore, while three sets of Service estimates are presented each year, not only is political rivalry likely to obscure the main issues in debate on the votes, but it is also likely to prejudice the drawing up of a correct balance between the requirements of the individual Services.

Consequently, it is contended that there should be a Ministry of War. The creation of such a Ministry would cut down a number of "overheads," prevent overlapping, and would enable one Service Estimate to be presented annually which would give a much clearer picture of our defense requirements and the accompanying bill. A further advantage would be the elimination of political rivalry, which is undesirable, without eliminating the healthy inter-Service competition in efficiency which is not only desirable but essential.

In the writer's opinion the cumulative lessons of the War clearly demonstrate the need of a single War Ministry, and it would appear that one could be created with great advantage to the maintenance of unity of purpose and effort without in any way interfering with the sovereign status of the individual Services. The writer is well aware that the proposal is not new and that in the past it has been rejected on various grounds, such as the argument that no one man could carry out the duties of Minister of War and that the Ministry would be too unwieldy to function efficiently. Rightly or wrongly, the writer is not impressed with any of these arguments. So often they are specious and advanced merely to safeguard vested interests, which in themselves are frequently the obstacle in the way of achieving unity of either purpose or effort. The present machinery, with a good deal of trial and tribulation, has been made to work. But it must be nationalized if we are to avoid the perils which will beset the way of those who are charged with the responsibility of maintaining unity in the trinity of the Services as the War recedes into the background and the problems of peace and social, as opposed to national, security rise uppermost in the public mind, and in the arena of party politics.

Should a Ministry of War be created, it follows that it must be served by a Combined Staff. The creation of such a staff has frequently been suggested and the proposal rejected by Parliament for reasons which may have been sound in default of the existence of a single Ministry of War. The two proposals appear to go hand in hand; if one be accepted, the other then follows as a natural corollary and discussion of the pros and cons appears unnecessary. Perhaps the creation of the Supreme Headquarters of the Allied Expeditionary Force in Europe provides a good and topical example of what can be done in the way of integration, provided the will and the urgency exist. At S.H.A.E.F.—an organization of some magnitude—officers of our own three Services, together with those of a great Ally, work with harmony and efficiency and in the closest co-operation, dealing daily with operational and administrative matters of the first importance. Therefore it would appear reasonable to assume that a similar combined staff would also prove efficient under peace-time conditions when none of the complications inherent in dealing with an Ally are entailed.

It is postulated that the proposed Combined Staff should be presided over by the existing Chiefs of Staff Committee with the Minister for War as Chairman and titular head. The existence of a properly constituted Combined Staff would automatically remove the need for many of the other committees which at present serve the Chiefs of Staff in the realms of operations, intelligence, economic and political warfare, and kindred subjects, and whose deliberations so often clog the wheels and delay decisions. In fact, there is no intention of tinkering with that part of the machinery which fits in with our three Service organizations and which, moreover, appears to have stood the test of war, *i.e.*, the Chiefs of Staff Committee. Nevertheless various misnomers should be rectified. For example, the title of Chief of the Imperial General Staff is a misnomer, as there is no real *Imperial* General Staff and the holder of the appointment is co-equal with the other Chiefs of Staff. Again, the label War

Office is obviously misleading and, although traditional, could be changed with perchance a good psychological effect on public opinion, and without affecting the morale or well-being of the Army which it serves.

Before closing this dscussion on the lessons of the War and the resulting conditions, the writer must emphasize two final but important lessons which are considered to have a bearing on the subject.

First, it is essential to keep abreast of scientific research and development so that the results can be applied to Service needs quickly and in a unified manner. This is bound up with design and production, which in the past have frequently been haphazard and lethargic and without any real unity of purpose from the inter-Service standpoint, despite the activities of the numerous boards and committees set up between the wars. The proposed Combined Staff should be given the mandate to preside over all such committees and establishments, with the object of co-ordinating their activities and issuing clear cut directions as to Service requirements and specifications. It is a mistake to produce a weapon or article of equipment and then attempt to evolve tactics to suit it, the reverse should normally be the procedure.

Secondly, if unity is to be properly maintained, some solution must be found to the problem of Imperial "policing." In the past, many units of all three Services, especially of the Army, were scattered throughout the Empire in small oversea stations where no facilities existed or opportunity was afforded for any form of combined training even on the lower levels. This state of affairs reflects adversely on the maintenance of unity of purpose and effort and may contribute towards disaster if we should again become the victims of aggression in a future total war.

Summary.

As a result of the foregoing examination of the lessons of the War—an examination which is perforce cursory owing to lack of knowledge of *all* the facts, the writer concludes that the first essential in maintaining unity of purpose and effort after the War is education. Further, this education must start at the beginning of an officer's career before he is commissioned. To meet this need, the creation of an Imperial Defense University, at which all aspirants for Commissions must graduate, is recommended.

The next essential is the institution of a Combined Staff College, which would be attended by selected officers of all three Services. In addition, throughout his career, an officer should carry out frequent attachment to arms and Services other than his own and should be given ample flying experience.

These proposals should result in a proper understanding of inter-Service problems by all officers throughout their career, and in the creation of a body of highly-trained commanders and staff officers competent to deal with the complications of modern total war in three elements, imbued with a singleness of purpose, and sharing a common doctrine.

To maintain unity at the higher levels, a Ministry of War has been proposed, to be served by a Combined Staff and represented in Parliament by one Minister. The Chiefs of Staff Committee should remain and preside over and direct the activities of the Combined Staff in accordance with the national policy as laid down from time to time. In this connection the writer is of opinion that the national policy as regards defense and foreign relations should be kept clear of party politics, as it is unfair to expect unity of purpose and effort in the Services if the premium which the country is prepared to pay for defense is likely to vary every time there is a general election. Discussion on such matters is, however, outside the scope of this essay.

We must be prepared for the growth of public apathy towards the Services as the years roll on, and therefore they must have good publicity. Publicity, hateful as it may be to many in the Services, is an integral part of modern life, and in fact the writer feels that the need for its exploitation is one of the minor lessons of the War. Our American Allies give great attention to it in relation to their armed forces and general war effort, and it would appear necessary in the post-war years to move with the times by making use of all the resources of propaganda to present to the public a unified picture of the purpose and activities of our soldiers, sailors and airmen.

May it also be suggested that propaganda in favor of the armed forces be closely linked with education on a nation-wide basis as to the meaning of the great heritage of Empire which is ours. It is essential that every citizen should understand the necessity for, and problems of, Empire defense and thereby take a pride in the efficiency and well-being of the Forces which safeguard our national security.

No attempt has been made to suggest any internal re-organization of individual Services. Obviously when the lessons of the War are collated and digested some re-organization will be found necessary; recruitment on a voluntary basis may have to be abandoned and the terms and conditions of service will almost certainly have to be improved. In this connection, if a rate of pay and allowances common to all three Services was brought in, it would help in promoting the mutual trust and good fellowship which, at any rate among the lower ranks, can do much to promote unity in the general effort.

To sum up. By the Grace of God and our national capacity for improvization and compromise we have survived an act of aggression which found us unprepared in almost every requisite for waging total war. Reforms are obviously needed. Whether or not they follow the lines suggested by the writer, it is essential that once the War is over they should be carried out with speed and determination while events are fresh in the public mind, and while we have with us to advise and direct during the transition period those who have carried the heavy responsibilities of the conduct of the war to final victory.

VIBRATION PROBLEMS IN THE DESIGN OF MARINE OIL ENGINES.

A comprehensive but easily understandable discussion of the vibration of marine internal combustion engines is contained in this paper, written by E. H. Woodhead, B. Sc. This essay is reprinted from Volume 88 Part 7, June 1945, of the Transactions of the Institution of Engineers and Shipbuilders in Scotland. It was awarded first prize in the essay competition, March, 1945.

The adoption of the steam turbine as a prime mover in highspeed passenger ships somewhat reduced the magnitude of the problem of vibration, but in recent years this problem has once more been intensified by the growing use of the heavy oil engine for small and medium sized vessels. The object of this paper is to point out the possible causes of vibration in ships, and to outline the various methods whereby the magnitude of the disturbing forces may be reduced.

Ship Vibration Periods. The frequency of any periodically recurring force must not coincide with the natural frequency of any part of the ship's structure, otherwise damage or bodily discomfort may result. Vibration in ships occurs in two main forms—as a vibration of the whole structure, or as local vibration in some isolated part of the vessel. This

latter form may often be obviated after the vessel has been completed, for example, by local stiffening, etc., but not so the former type. This problem therefore calls for co-operation, in the early stages of design, between the naval architect and the designers of main propelling or auxiliary machinery.

The structural vibration of ships may be classified as vertical, horizontal or torsional, the first two being flexural vibrations; these two types may take place with any number of nodes, from two upwards, in the ship's length, whilst the torsional vibrations may have any number, Figure 1.

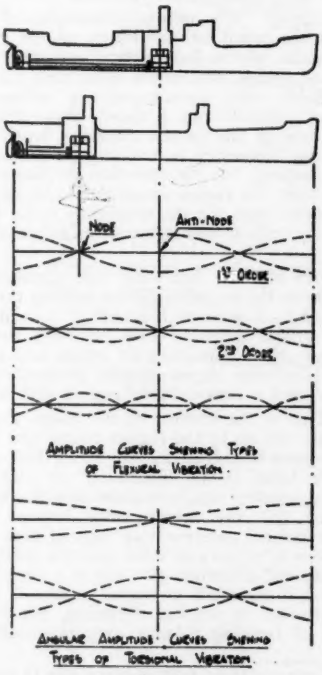


FIG. 1.

The modes with the minimum number of nodes are the ones with which the designer is usually concerned since these, in addition to being the frequencies that are the most dangerous, are the ones that can be predicted with the greatest certainty. The torsional vibration which in an average ship has a frequency, in a single-node form, of four to six times that of the two-node flexural vibration is generally not detected as an objectionable vibration mode. In the design office, empirical formulae are used for calculating these natural frequencies. These only require knowledge of the class of vessel and its leading hull dimensions. This aspect, amongst others, has been dealt with elsewhere in a comprehensive manner.[1, 2] Whilst these formulae take no account of the effect of water

moving with the ship, the effect of change of draught, the influence of the composite character of the structure—riveted joints, etc.—they nevertheless do assist the naval architect to estimate the important periods at an early stage in the ship design. Once the principal dimensions have been fixed, the vibration frequencies of a vessel can only be modified within close limits by variations in detail design. It is a matter for individual consideration in each case whether weight distribution of the ship is capable of much variation, for example, by ballasting. Concentration of weight at the nodes increases the frequency, whilst concentration of weight at the anti-nodes decreases the frequency of vibration.

Choice of Engine Speed. The natural frequencies of the vessel should be so arranged that the speed of revolution of the main engine is, if possible, below the value of the hull critical, as otherwise with present-day proportions in hull design, this would mean very high rotational speed in all engines, probably with correspondingly reduced propulsive coefficients. Auxiliaries generally run at speeds above the lower order ship criticals. The amplitude of any forced vibration depends upon the proximity of the disturbing frequency to the natural frequency of vibration. Thus, in the present instance, for the vibration amplitude to be 20 per cent of the resonant amplitude, the engine speed should be about 4 to 8 per cent below the resonant speed, and for the amplitude to be 10 per cent of the resonant amplitude, the corresponding speed reduction should be about 12 per cent.

Number of Propeller Blades. Torsional hull vibrations may be caused by regular impulses from the propeller blades passing through the aperture of a single-screw vessel or close to the hull of a twin-screw ship. The number of propeller blades (usually three or four) should be chosen so that there is no undesirable combination of engine and propeller impulses, for example, a three-cylinder engine should preferably be fitted with a four-bladed propeller, and a four-cylinder engine with a three-bladed one.

Engine Balance. Due to the motion of the piston connecting rod, etc., forces and couples are set up in the engine frame and shaft. To ensure freedom from coincidence with the corresponding hull natural frequency, special care has to be taken in the "balancing" or counteracting of some of these forces. The problem resolves itself into the balance of (a) the rotating masses, and (b) the reciprocating masses. The unbalanced rotating masses in a normal reciprocating engine, that is, the crank pin, the unbalanced portions of the crank webs, and the rotating portion of the connecting rod and big-end assembly, give rise to a centrifugal force which rotates in the direction of the crank at engine speed. It thus has a varying component in a horizontal or vertical direction, but may be completely balanced by the use of rotating balance weights usually attached to the crank webs.

The inertia of the reciprocating masses gives rise to an unbalanced force in the line of reciprocation only. This force is of varying magnitude, and in the case of engines of slow or medium speed is

$F = W(\omega^2 r \cos\theta)/g + W[\omega^2 r(\cos 2\theta)/n]/g$ lb. for one cylinder line where W = total weight of reciprocating parts (lb.)

r = crank radius (in.)
ω = angular velocity of crank (radians per sec.)
θ = angular displacement of crank from I.D.C.
n = ratio of connecting-rod/crank length
g = acceleration due to gravity (in. per sec. per sec.).

The first component is termed the primary inertia unbalanced force. The maximum value of the second component, that is, the secondary inertia unbalanced force, whilst only of magnitude $1/n$ times the maximum value

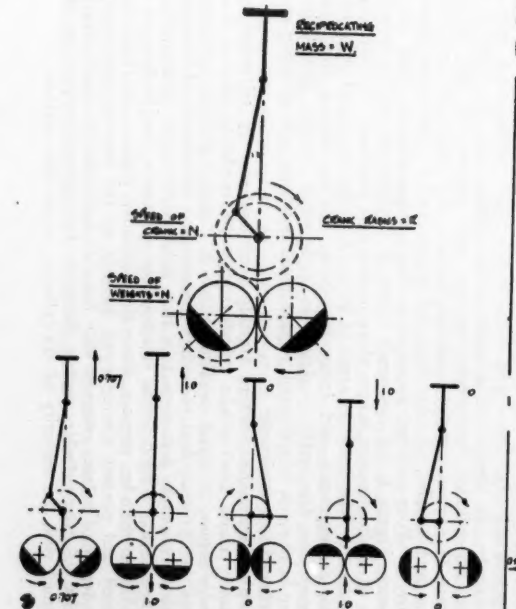


FIG 2(a) BALANCING SYSTEM FOR PRIMARY FORCES (RECIP.)

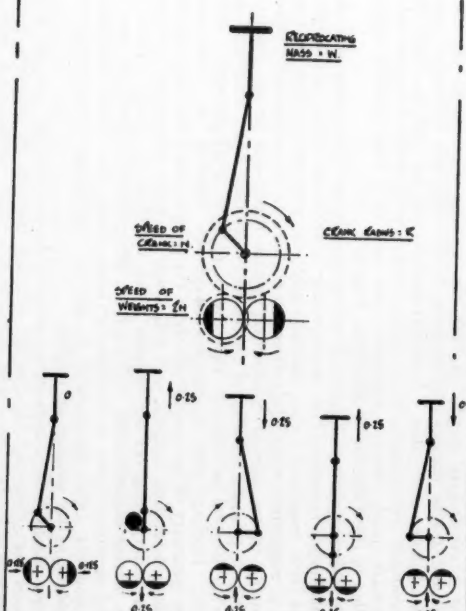


FIG. 2(b). BALANCING SYSTEM FOR SEC'RY FORCES.

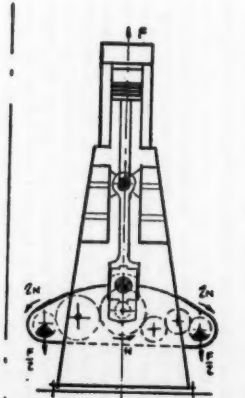


FIG. 2(c). ARRANGEMENT OF SECONDARY BALANCE WEIGHTS FITTED TO ALLEN 4 CYL. 4 S-C. ENGINE. ("EMPRESS OF AUSTRALIA".)

DIAGRAMS REPRODUCED FROM: W. KER WILSON'S "BALANCING OF OIL ENGINES" (PUB. GRIFFIN)

of the primary force, occurs four times per crank revolution, as compared with twice per revolution for the latter.

The addition of a single balance weight may be used to eliminate the primary inertia force in the line of stroke at the expense of introducing a new and equally disturbing horizontal force. Alternatively, a smaller weight may be used so as to leave equal unbalanced forces in both the vertical and horizontal planes. Secondary reciprocating forces cannot even be partly balanced by a rotating weight attached to the crankshaft. Complete balance may be obtained, however, without introducing horizontal unbalance by arranging two weights symmetrically below the engine center line (to avoid introducing a transverse couple) and driven by gearing at a crankshaft speed, so that the vertical components of their centrifugal forces balance the primary forces, and the horizontal components balance each other. A similar method may be used for balancing the secondary reciprocating forces if the balance weights are driven at twice crankshaft speed. Such a scheme[3, 4] was used on a four-cylinder engine installed in the *Empress of Australia*, Figure 2.

The various unbalanced forces if acting in different planes may give rise to unbalanced couples. The reciprocating couples are fixed in direction, whilst their magnitudes vary harmonically; the rotating couples are constant in magnitude whilst their direction changes as the crankshaft rotates. Normally, in an internal combustion engine there will be no resultant rotating or primary unbalanced forces to be handled since considerations of firing interval will ensure that the crankshaft itself possesses static balance. Engines with asymmetrical cylinder spacing, or non-mirror image symmetry of the crankshaft about the engine center line may possess unbalanced rotating couples, and will always possess unbalanced primary and secondary reciprocating couples. This condition frequently occurs in large marine engines with odd numbers of cylinders, or which have a central camshaft, drive, an auxiliary scavenge pump, etc. These auxiliaries can, however, often be oriented to give an appreciable reduction in the magnitude of the unbalanced couples.

In marine propelling engines, to ensure positive starting from all positions of rest, four and six are the smallest number of cylinders which are permissible for two- and four-stroke cycle single-acting engines respectively. In double-acting engines the number may be reduced to three. Six-cylinder four-stroke engines with cranks at 120 degrees (Figure 3) possess complete external balance of primary and secondary forces and couples, as also does the eight-cylinder four-stroke engine, Figure 4. Four-cylinder, two-stroke, single-acting engines, with crank sequence, Figure 5, are frequently found in single-screw marine installations of medium power, where there is plenty of headroom and the speed is moderate. The crank sequence of Figure 6 is superior to all other two-stroke arrangements, and hence two-stroke engines having this crank sequence are frequently employed in multi-screw marine installations, where head-room is restricted, engine speed is higher and vibration must be reduced to a minimum.

In auxiliary engines where starting considerations are of minor importance, three, five or six cylinders may be employed. For a four-cylinder engine, the crank sequence shown in Figure 5 gives no unbalanced forces, but primary and secondary couples are unbalanced. Unbalanced couples are usually less pernicious than unbalanced forces, particularly in engines having a rigid frame construction. However, the tendency is to avoid four-cylinder engines since three-cylinder engines are less complicated and possess almost equal balance to the four-cylinder engine. The degree of balance obtained with five-cylinder engines is much superior to that of four-cylinder engines, being in fact almost as good as that obtained with the majority of six-cylinder, two-stroke engines.

Engine Location. The location of the engines in a vessel determines whether or not the unbalanced forces or couples are likely to give rise to undesirable vibration. An engine having a resultant unbalanced force located near an anti-node will accentuate hull vibration, but will have no influence if placed at a node. On the other hand, an engine with a resultant unbalanced couple placed at an anti-node will have no influence, but if situated near a node, the opposite effect will obtain. Thus engines located aft, for instance, in tankers, should have the unbalanced couples made as small as possible. For engines amidships unbalanced forces are of importance in the case of the first order hull vibration, and unbalanced couples in the case of second order hull criticals. (Figure 1.)

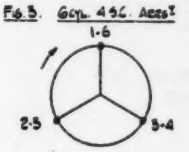


Fig.5. 4cyl. 2SC. Arrgt.

Fig.6. 6cyl. 2SC Arrgt

Engine Frame Vibration. Where inherent balance is present in the crankshaft without counterweights, and if full balance weights are not used, then the balance is obtained by opposing one set of forces or couples by another, and hence there must be transmission of forces and couples through the shaft and engine frame. If these parts are not sufficiently rigid then serious vibrations may be induced. If, on the other hand, full balance weights are used, then the revolving forces are counteracted at their source and there is no bending moment due to revolving masses on the shaft or frame; there will, of course, still be the bending moments due to the internal unbalance of the reciprocating forces. In large and medium sized engines, such as are used for marine applications, the crankshafts are usually relatively heavy and rigid, and the number of main bearings is normally at least one more than the number of cylinders. Thus, the correct positioning of balance weights is not of such importance as in the case of the light transport engine, although naturally balance weights can be used to reduce crankshaft bearing loads.

Due to the obliquity of the connecting-rod a transverse force is always induced, which is dependent upon the gas pressure acting on the piston and the inertia of the reciprocating masses. As this force acts at the main bearing and piston in opposite directions, a frame couple is produced which equals in magnitude the torque exerted on the crankshaft. This "torque reaction couple" in each individual cylinder tries to rock that cylinder about its point of support. With certain cylinder arrangements which give rise to a high torque ratio, this twisting action has to be carefully considered in the design of very long crankcases.

In addition to the above sources of vibration, every engine frame possesses a natural frequency of vibration in both a horizontal and a vertical

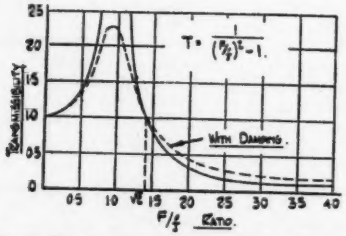


FIG. 7. RELATION BETWEEN TRANSMISSIBILITY FACTOR AND FREQUENCY RATIO.

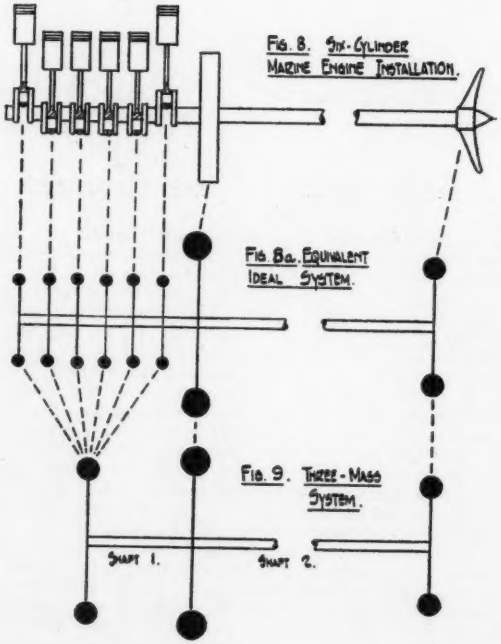


FIG. 8. SIX-CYLINDER MARINE ENGINE INSTALLATION.

FIG 8a. EQUIVALENT IDEAL SYSTEM.

FIG. 9. THREE-MASS SYSTEM.

plane. These frequencies may be determined by considering the engine to be a non-uniformly loaded cantilever fixed at the base.[2] The frequency of vibration of an engine on a rigid seating is naturally higher than when the engine is mounted on a tank top, as also is the frequency of a twin-engine installation when the two engines are tied together than when the engines are separate. If a critical frequency is calculated to occur at about the service speed of the engine, then thickening of the tank-top plating or the fitting of pillars to act as 'thwartship stoppers to the end cylinders may improve matters. Since the frequencies of vertical vibration of an engine are generally high, they are usually well above the main engine speed, but they might cause trouble with a high-speed auxiliary mounted on a light seating. Such a seating may be stiffened by welding.

Engine and Seating. The transmission of noise or vibration from a reciprocating engine to the vessel hull may be reduced by the production of a quiet-running engine and the isolation of the engine from the hull. Since there is an economic limit to the first requirement, considerable attention should be paid to the engine seating. Little advantage is to be gained by mounting an engine on cork (a 3-inch thickness will only absorb frequencies above about 670 v.p.m.). A rubber-pad mounting has a lower limit of about 170 v.p.m., and is mainly effective in absorbing low amplitude vibrations. A spring support system offers the most favorable form of mounting for all types of engines. The springs may be of the conventional type or of the rubber-bonded-to-metal type.

The transmissibility of vibrations by a mounting is shown plotted (Figure 7) against the ratio F/f, where F is the frequency of the disturbing force, and f is the natural frequency of the support system. Only for frequency ratios greater than $\sqrt{2}$ does a reduction of vibration occur, hence a mounting should be selected which will give a natural frequency of vibration as far below that of the disturbing frequency as is practicable, bearing in mind that in order to give such low frequencies, a large static deflection is obtained.

Large bed deflections create problems such as the coupling of the main engine to the thrust block, the preservation of crankshaft alignment, and alignment with the tunnel shafting, the attachment of cooling water pipes, exhaust pipes, etc., to the engine. Moreover, if the suspension system is to operate as designed, the engine must be free of the ship's structure no matter how the ship rolls or pitches. The unbalanced torque reaction (that is, the tendency to rock the engine in a direction opposite to the crankshaft rotation) is an added complication with propelling machinery. In general, for propelling engines of large size, rigid bolting to the seating or tank top appears to be essential. Flexible mountings become really effective for higher speed auxiliary sets in which the engine and generator or compressor are one complete unit and the torque reaction is zero.

Torsional Vibration. Torsional oscillations are present to greater or less extent in all reciprocating engines due to the periodically varying torques. These torques, gas and inertia give rise to systems of torsional vibration which are quite independent of and different from any other vibrations, including those which may arise from engine unbalance or shaft "whirl." Since the engine shaft is not torsionally rigid the variations of engine torque do not produce angular acceleration of the shaft as a whole, but rather an acceleration combined with a vibrational twisting of one end of the shaft system relative to the other. The shaft system and its attachments (i.e., reciprocating masses, flywheel, propeller, generator or other driven unit) can be reduced mathematically to an equivalent system of a shaft of uniform diameter and a number of rotating masses. The equivalent system for an engine and propeller is shown in Figure 8(a). Such a system can vibrate torsionally in several ways or modes, each mode having its own independent natural frequency.

The three-mass system, Figure 9, may vibrate in one or two ways:

(a) With a single node in shafts (1) or (2) and the corresponding end mass vibrating opposite in phase to the remaining two;
(b) With two nodes, one in each connecting shaft; the two end masses vibrate in phase and the center one opposite in phase to the end ones.

Each mode of vibration has its own natural frequency and in general for a system of N masses connected by (n—1) shafts there are (n—1) modes of vibration. Further, the lowest value of the natural frequency is associated with the single-node system, the second lowest value with the two-node system and so on.

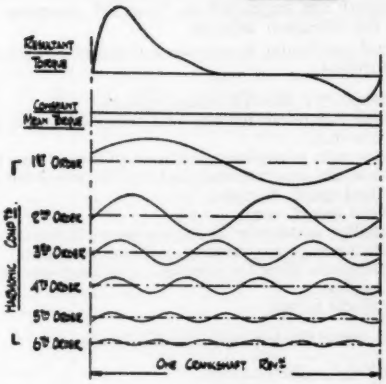
In an internal combustion engine the torque maintaining the shaft vibration is the sum of the cylinder and inertia torques, and, for one cylinder of a two-stroke engine, is as shown in Figure 10. The turning moment diagram being periodic can be analyzed into simple harmonic components as shown, these being of different frequencies. If the engine speed is such that the frequency of one or other of these torque components synchronizes with any of the natural frequencies of the system, then resonance occurs and the engine is said to be running on a "critical speed." Thus, if the engine speed is half the single-node natural frequency the synchronization is taking place with the second order component and the critical is a second order single node. The fifth order will occur if the engine speed is ⅕ the natural frequency, and so on. In two-stroke engines the critical speeds can only be integral orders, but in four-stroke engines where the periodicity of the torque curve is half the crankshaft speed, there are also half-order criticals. The order number is always reckoned relative to the crankshaft speed. Order numbers which are integral multiples of the number of engine cylinders are known as major criticals whilst the others are minor criticals. In general, the higher the order number the less severe is the critical, althought a major order number is always much more severe than a proximate minor order.

The problem of the design engineers is to adjust the natural frequencies so that there are no critical speeds near the running speed range of the engine. Whilst many failures of shafting have been traced to abnormal vibration at critical speeds, satisfactory operation implies more than freedom from actual mechanical breakdown; a definite guarantee of a smooth operating speed range with no perceptible vibratory disturbance is a feature of most marine specifications. The particularly insidious nature of torsional vibration is due to a capacity for destructive action without displaying the external symptoms which are usually very noticeable with other forms of vibration, in addition to which, the fatigue limits for alternating torsion are invariably about one half the fatigue limits for alternating flexure.

The natural frequencies having been calculated by any of the standard methods, for example, that due to Bradbury[5] or Holzer's frequency table method,[6] the next step is to estimate the vibrational amplitude and hence corresponding nodal stress. This problem is generally solved by equating the energy input per cycle due to forcing torques at steady conditions of resonance, to the energy absorbed by damping. The sources of damping may be summarized as follows:

(1) Damping due to ship's propeller, that is, continual torque changes due to variable slip and constant speed of advance, the damping being proportional to the vibrational velocity.
(2) Hysteresis damping—due to energy being absorbed by a material under cyclic stress;
(3) Engine damping—for example, energy absorbed at the bearings by oil films, etc.;

FIG 10 TURNING MOMENT DIAGRAM FOR 2 S.C. ENGINE.



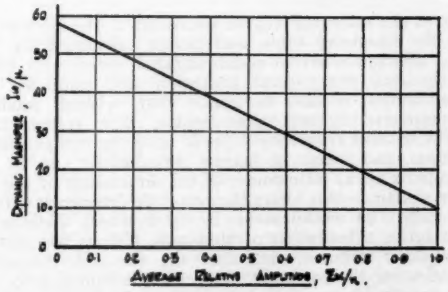


FIG. 11. ENGINE DAMPING. (SHANNON FACTOR).

(4) Apparent damping due to the natural frequency being variable over different parts of the vibration cycle, for example, variation of the inertia of reciprocating parts for different crank positions, cyclic fluctuations, of speed, etc.

For marine installations, where the ratio of the relative vibration amplitude at the propeller to that at the engine is large, it is generally assumed that propeller damping is the effective source of vibration energy dissipation in the system for the single node mode. For the two-node mode, Dr. Shannon[7] has suggested an "overall" damping factor which is proportional to the vibration velocity.

The forward end amplitude, θ, may be calculated for the single-node form by Dr. Dorey's formula:

$$\theta = (T_n \Sigma\alpha N^2_1)/(28.6 N T_1 \alpha^2_p \omega c) \text{ radians,}$$

where T_n = torque harmonic for the nth order vibration for one cylinder (lb.-in.).
$\Sigma\alpha$ = vector sum of engine cylinder amplitudes (from frequency table).
T_1 = torque (lb.-in.) required to turn the propeller at the rated full load speed, N_1 rpm.
N = critical speed, rpm.
α_p = propeller amplitude (from frequency table).
ω = vibrational phase velocity (radians per sec.).
c = constant to allow for presence of other forms of damping in the system.
28.6 = empirical factor.

For the two-node form, the forward end amplitude—

$$\theta = (T_n \Sigma\alpha)/(\mu\omega \Sigma\alpha^2) \text{ radians,}$$

where $\Sigma\alpha^2$ = arithmetical sum of the squares of the frequency table amplitudes.
μ = damping factor, calculated from Dr. Shannon's experimental plot of $I\omega/\mu$ to a base of $\Sigma\alpha/n$, Figure 11. I = equivalent moment of inertia per cylinder line, and n = number of cylinders.

The stress at the node per degree deflection at the forward end can be found from the frequency table, and having calculated the forward end amplitude, as above, the actual nodal vibration stress may be determined.

Having calculated the natural frequency and estimated the possible vibration amplitudes, it may be found that, without modification, the system is unsatisfactory and unacceptable. The system thus requires "tuning." The natural frequency depends upon the component inertias and shaft stiffnesses, and hence in marine installations can be adjusted by such modifications as (a) adjustment of the dimensions of the intermediate and propeller shafting—this alters the one-node frequency without modifying the two-node, (b) modifications to the flywheel, addition or removal of balance weights, substitution of aluminum pistons for cast iron, variation of crankshaft stiffness, etc., alter the two-node frequency without appreciably affecting the one-node. In certain instances, also, the one-node form can be greatly improved by substitution of a bronze propeller for an existing cast iron one or vice versa. In marine practice the one-node critical is normally below the operating speed for engines installed amidships and above it for engines aft. The two-node criticals are normally more numerous and criticals in the engine crankshaft can be very severe.

In geared drives special care has to be taken to avoid torque fluctuation at the gear teeth sufficiently great to cause separation and hammering. The torque at the gears must never be reversed and in practice should not fluctuate more than ±25 per cent of the mean torque. A carefully chosen flexible coupling between the engine and gear box may often improve

matters. These flexible couplings, which may be of the rubber-bonded-to-metal type or of the Bibby spring coupling type, may also be introduced in a shaft system to give a greater degree of flexibility than is practicable with the shaft dimensions in question. The Bibby coupling is used on very many marine installations, since, in addition to the flexibility which is introduced, it possesses an apparent "damping" characteristic, which prevents the building up of large vibration amplitudes. The engine firing order has a considerable influence on the amplitudes of torsional vibrations, hence alteration of firing order is another "tuning" method. Because of balance considerations, however, this method only applies to four-stroke engines.

If it is not possible to keep the running speed range clear of critical speeds by the above, then recourse must be made to some (correctly designed) form of damper. This may be in the form of a friction damper, a dynamic absorber (bonded-rubber or pendulum type) or a detuning flywheel, which may be an auxiliary flywheel mounted on a Bibby coupling.

Torque Variation. The irregularity of torque given by a reciprocating oil engine results, as previously mentioned, in a variation of the angular speed of the propeller. The propeller thrust which is thus fluctuating about its mean value, adds a varying load to the mean load on the blades, shaft and thrust block. This may in some instances be the cause of axial shafting vibration or propeller blade vibration. This propeller thrust variation produces a variable wake in which the propeller is working, and this again may result in blade vibration. The cyclic irregularity of speed is naturally less for two-stroke engines than four-stroke engines, and, in general, for even numbers of cylinders is less for single-acting engines than for doubles-acting engines, but for odd numbers of cylinders the opposite condition holds.

Vibration Measuring Instruments. Vibration instruments may be classified as those used for frequency measurements and those used for motion analysis. For very slow vibrations, counting by observation may suffice. Stroboscopes are also commonly used to measure frequency, whilst large amplitudes of vibration may be scaled off by observation, with or without a measuring microscope. Most vibration amplitudes are, however, too small for these methods, so vibrographs have to be used. Vibrographs of the mechanical kind are actually special types of seismographs. Thus, with a vertical or horizontal vibrograph the relative motion between the instrument frame and a heavy suspended mass, which remains at rest in space is measured. A rotational vibrograph or torsiograph measures the relative motion between a light pulley, which is driven from the shaft under investigation, and a flywheel, which is connected to the pully by light springs, and has sensibly constant angular velocity. By a system of links this relative motion is recorded on a strip of either paper or celluloid. Timing waves are put in the same strip for comparing frequencies.

Electrical instruments may be of the resistance, capacitance, electro-magnetic or piezo-electric type. The output from pick-ups of the above types is applied to either an electro-magnetic or a cathode-ray oscillograph. The electro-magnetic pick-up depends upon the movement of a coil through a magnetic field, the voltage change in the coil being proportional to the velocity movement. The velocity may be converted to displacement by electrical integration of the voltage before applying it to the oscillograph. With the piezo-electric type, the voltage change across the crystal is proportional to the acceleration, hence the displacement can only be obtained by integrating electrically twice. Vibrographs of the mechanical type are at present more robust, and the equipment is less bulky than for their electrical counterparts, hence the former are generally used for vibration measurements on board ship.

Conclusions. It has only been possible to touch lightly on some of the disturbing influences connected with marine machinery. It will be seen, however, that the relationship of ship and machinery is a most important matter. Although in the past, from the point of view of vibration, many successful ships have been constructed, this has often been due to a certain measure of luck. In view of the large number of investigations carried out by specialists, vibration may now be considered to be something which should be foreseen, but which can be reduced to a minimum if it is found to occur after the vessel has been completed.

Acknowledgments. The Author wishes to thank the directors of the Brush Electrical Engineering Co. Ltd., and Petters Ltd., Loughborough, for permission to publish this paper.

BIBLIOGRAPHY.

1. "Ship Vibration—A Comparison of Measured with Calculated Frequencies," by F. H. Todd. Trans. N.E. Coast Inst. Eng. & Shipbldrs., 1932-33, vol. 49, p. 259.
2. "Some Vibration Problems from the Marine Engineering Point of View," by T. W. F. Brown. Trans. N.E. Coast Inst. Eng. & Shipbldrs., 1938-39, vol. 55, p. 127.
3. "Possible Vibration of a Ship's Hull under the Action of an Unbalanced Engine," by W. E. Dalby. Proc. Inst. Mech. Eng., 1928, vol. 2, p. 747.
4. "The Balancing of Oil Engines," by W. Ker Wilson. 1929. C. Griffin & Co., London.
5. "The Geared Marine Oil Engine," by C. H. Bradbury. Proc. Inst. Mech. Eng., 1933, vol. 125, p. 461.
6. "Die Berechnung der Dreischwingungen," by H. Holzer. 1921. Julius Springer, Berlin.
7. "Damping Influences in Torsional Oscillation," by J. F. Shannon. Proc. Inst. Mech. Eng., 1935, vol. 131, p. 387.
8. "Strength of Marine Engine Shafting," by S. F. Dorey. Trans. N.E. Coast Inst. Eng. & Shipbldrs., 1938-39, vol. 55, p. 203.
9. "Practical Solution of Torsional Vibration Problems," by W. Ker Wilson. 1941. Chapman & Hall, London.

ATOMIC ENERGY,
A SURVEY OF ITS NATURE AND POSSIBILITIES.

The devastating effect of the atomic bomb has focused the attention of the world on atomic energy. In this article written by J. M. A. Lenihan, M.Sc., of the Physics Department, King's College, Newastle-on-Tyne, and reprinted from the September 1945 issue of the Shipbuilder and Marine Engine-Builder, a simple explanation of the disintegration of the atom is presented.

The utilization of atomic energy, a prospect which has for so long been the goal of much scientific research, is now a practical possibility; in the following notes is given a brief and necessarily incomplete account of this new branch of applied science, with some speculation as to its future development.

Atomic Physics.

It is necessary first to recall the elementary facts of atomic physics. The atom is the smallest portion of matter which can have a stable, independent existence. Its size depends on the substance to which it belongs, but is never very great; the number of atoms in a thimbleful of water is about the same as the number of grains of sand which would be needed to fill a trench a mile wide and a mile deep, stretching from London to Cairo. Knowledge of atomic

structure must, therefore, be obtained indirectly; none the less, it is fairly comprehensive. The atom consists of a nucleus, with which is associated nearly all the mass and a positive electric charge, and a number of negatively-charged electrons. The nucleus occupies only a small space—it is, relative to the size of the atom, about as large as a fly in a football field. It is now regarded as being composed of protons, each carrying one unit of positive charge, and neutrons, each of which has the same mass as a proton, but no charge. The mass of the atomic nucleus, referred to that of oxygen (= 16) as the standard, is the atomic weight of the elementary substance to which it belongs. The number of protons in the nucleus is the atomic number. Atomic numbers range from 1 (hydrogen) to 92 (uranium) for the known chemical elements. The number of electrons in an atom is equal to the number of protons, and therefore to the atomic number; and since chemical reactions and many physical processes involve an interchange of electrons, the atomic number of an element determines most of its properties.

Table I. gives in summary form the relevant characteristics of the fundamental entities of atomic physics.

TABLE I.—PROPERTIES OF SOME OF THE FUNDAMENTAL PARTICLES OF ATOMIC PHYSICS.

Name.	Relative Mass.	Relative Charge.
Electron	1	−1
Proton	1837	+1
Neutron	1837	0
Alpha-particle	7350	+2

ISOTOPES.

The atomic number of oxygen is 8, and its nucleus therefore contains 8 protons. The atomic weight is 16, so that the nucleus also contains $16-8=8$ neutrons. Now, there is a rare substance with a nucleus containing 8 protons and 9 neutrons. This has an atomic number of 8, and must, therefore, be regarded as oxygen, though its atomic weight is 17, instead of the normal value, 16. A third substance with atomic number 8 and atomic weight 18, is also known. These three materials display the physical and chemical properties of oxygen, but have different atomic weights; they are known as isotopes of oxygen. Nearly all of the 92 elements have isotopes, in varying numbers; about 600 are known altogether.

RADIOACTIVITY.

So much for the structure of the atom. Let us now turn to an early prototype of the atomic bomb—the radium atom. Most of the elements between lead (atomic number, 82) and uranium (atomic number, 92) in the well-known Periodic Table exhibit the phenomenon of radioactivity, which, it is known, results from a spontaneous disintegration of the nucleus, accompanied by the emission of a variety of particles and rays—alpha- or beta-particles and gamma-radiation. An alpha-particle (which is otherwise recognized as the nucleus of a helium atom) is composed of two neutrons and two protons; a beta-particle is simply an electron, while gamma rays are X-rays of short-wave length. In the case of radium, which has an atomic weight of 226 and an atomic number of 88, the loss of an alpha-particle reduces the mass of the nucleus to 222 units and the nuclear charge to 86, corresponding to a different element—actually the gas radon. As soon as it is formed, however, the radon begins similar radioactive decay, giving radium *A*; and the process continues in several stages, until, eventually, a stable isotope of lead is reached. It should be noted that the atoms of a radioactive substance do not all break up at once; the decay follows an exponential curve. With radium, about

half the atoms "explode" in the first 1600 years, a further quarter during the next 1600 years, and so on. It is remarkable that the rate of disintegration is not influenced by any external factors, such as pressure and temperature. For a particular atom, its occurrence is unpredictable and spontaneous.

The amount of energy released in radioactive processes is very considerable; 1 pound of radium, in decaying to lead, would yield energy equivalent to 7×10^9 Btu.; so that radium, considered as a fuel, is half-a-million times more effective than coal.

These figures, however, are not of much practical significance, because 1 pound of coal can be made to give up its energy in a few seconds, while 1 pound of radium would not "burn itself out" for several thousand years. Nevertheless, the amount of energy available in atomic disintegration is so great that the prospect of extracting it at a useful rate has interested physicists for many years, and information recently disclosed concerning the atomic bomb suggests that the problem has now been solved.

Nuclear Fission.

Radioactive transformations and artificial disintegrations (produced with the aid of cyclotrons and similar high-voltage devices) all involve the removal from an atom of a small portion of its mass. The atomic bomb, and other means of releasing atomic energy likely to be available in the not-distant future, depend for their operation on the division of an atomic nucleus into two pieces, of more or less equal size—a process known as nuclear fission, which does not occur in Nature. It was discovered, at first unknowingly, 11 years ago, in Rome, by Fermi, who found that uranium atoms could be broken up by "bombardment" with slow-moving neutrons, giving products which could not be identified with certainty, but which were thought to be elements hitherto unknown, with atomic numbers greater than 92. It is said that Fermi proposed to name his first new element Mussolinium, but changed his mind when he found that it was very unstable! In 1939, Hahn and Strassman, in Germany, showed that the disintegration products of uranium fission are not new substances, but atoms of elements, such as barium, krypton, iodine and tellurium, from the middle of the Periodic Table. It was later found that only the rare isotope of uranium, of atomic weight 235, can undergo the fission process, the energy released being many times that of any previously-known nuclear reaction.

Chain Reactions.

Each atom of uranium, in breaking up, produces at least two neutrons, each of which is capable of producing another atomic disruption, and will do so if it penetrates a uranium nucleus before escaping from the scene of the experiment. The possibility of a reaction which, once begun, will continue with rapidly-increasing frequency, now becomes apparent. Two conditions must, however, be noted:—

(1) Fission is produced only by slow neutrons; those ejected by the exploding uranium atom travel at a very high speed and must be retarded if the reaction is to continue. For this purpose, materials containing hydrogen have been found suitable, and, in the atomic bomb, "heavy water"* is apparently being used.

(2) The fission produced by neutrons occurs only if they penetrate atoms of uranium 235; any which escape without doing so make no further contribution to the explosion. It is therefore necessary to have a moderately large piece of uranium, and calculation shows that about 1 pound should be enough to ensure a chain reaction.

The Atomic Bomb.

A major difficulty to be surmounted in the attempt to apply the principles outlined in the foregoing to the preparation of an atomic bomb is the production of a sufficient quantity of uranium 235. This isotope occurs in pitch-

*Heavy water contains deuterium, an isotope of hydrogen, of atomic weight 2, in place of ordinary hydrogen.

blende, in association with the common isotope, of atomic weight 238, in the proportion of 1: 139; and, since the two substances are almost indistinguishable by any of the usual methods, their separation is an intricate and tedious process. It may be presumed that this circumstance has accounted for a large part of the expenditure on the atomic-bomb project. It is probable that the explosion is self-starting, since a few neutrons are always present in the atmosphere; but, in any case, a minute quantity of radium mixed with beryllium would produce an ample supply.

Application of Atomic Energy.

The application of atomic energy to the arts of peace is of profound importance and significance, and must be seriously considered. The fission of uranium 235 does not, at first sight, appear to be a practicable method of releasing subatomic energy, since it is necessarily of an explosive nature. With 1 pound of uranium, about 25×10^{12} foot-pound of energy are liberated, but the process is all over in a thousandth of a second (*i.e.*, at a rate of 45 million-million horsepower!). It is therefore clear that further advances must depend on the development of a method by which the reaction can be retarded to a useful rate, so that the energy is released in a "trickle." It should not be difficult to find a suitable diluting agent, and, indeed, reports during the past few weeks suggest that several may already have been discovered. This is the crux of the future use of atomic energy.

In view of the great effort which has been expended in nuclear research during the war, it is reasonable to suppose that the phenomenon of fission has been induced in other substances besides uranium, and that many advances not yet revealed have been made. On the whole, it is permissible to be optimistic in regard to the possibility of extracting atomic energy in moderate quantities, but it must be remembered, that for some years, the cost is likely to be excessive. The calorific value of uranium 235 is about two million times that of coal; and since the total amount so far produced (at a cost of 500,000,000 lbs.) can hardly be more than a few tons, its further applications must await a considerable reduction in manufacturing costs.

To look into the future application of atomic energy, it is necessary to bear in mind the fundamental fact on which its production is based. The theory of relativity indicates that mass and energy are interchangeable, the relationship between them being:—

Energy = (mass) $\times$ (velocity of light)^2.

Calculations based on this relationship show that 1 pound of matter—if it could be transformed completely into energy—would release about 3×10^{16} foot-pound of energy. The explanation of the liberation of energy which accompanies radioactive changes is simply that the total mass of the products after disintegration is less than the original mass of the whole atom, the difference being converted into energy in accordance with the relationship just given. In the fission of uranium 235, the mass available for conversion to energy, though small itself, is comparatively great—about one-thousandth of the total mass. It must be said, however, that the possibility of more complete transformation of matter into energy is by no means remote.

Table II.—Approximate Calorific Values of some Fuels.

Name.	Btu. per pound	Ft.-pounds per pound	Hp.-hours per pound
Coal	14,000	11×10^6	5.6
Radium (in decaying to lead)	7×10^9	54×10^{11}	2.7×10^6
Uranium 235 (in fission process)	3×10^{10}	25×10^{12}	13×10^9
Matter of any kind (if completely changed into energy)	4×10^{13}	3×10^{16}	15×10^9

In Table II., the calorific values of a number of "fuels" are collected for the sake of comparison.

It is perhaps appropriate to conclude this brief survey by reference to a source of atomic energy which requires no upkeep, and which delivers an output much in excess of the world's requirements. The sun constitutes an atomic physics laboratory on a scale incomparably more vast than can be imitated in any terrestrial research station. In its interior, the disintegration and reconstitution of atoms proceeds continually, with the evolution of quantities of energy beside which the atomic bomb pales into insignificance. The average amount of energy received per spare mile of the earths surface in the form of solar radiation is equivalent to the combined output of all the electrical generating stations in Great Britian. It is therefore apparent that the effective utilization of solar energy is a prospect worthy of consideration, and there is no doubt that substantial progress could be made in 10 or 20 years if the problem were tackled with the determination which has led to the atomic bomb. Whether the expenditure of time and effort necessary to accomplish it will be considered worth while is, however, another matter.

POWER-FACTOR IMPROVEMENT.

The proper application of capacitors to induction motor loads overcomes many undesirable conditions. In this article, which was prepared for the A.I.E.E. Winter Technical Meeting by Messrs. W. C. Bloomquist and W. K. Boice of the Industrial Engineering Divisions of the General Electric Company and which was published in the July 1945 issue of the "General Electric Review," the authors discuss the practical considerations governing the choice of the method of power-factor improvement and give various examples.

Power-factor improvement of induction-motor loads by means of shunt capacitors has been a common practice for many years. A recent development is the practice of connecting the capacitors directly at the motor terminals in order to permit switching the capacitors and motor as a unit. This will not result in adverse motor operation if the amount of capacitance is selected properly. Little has been written regarding operating experience. However, some pertinent facts have been accumulated by capacitor and motor manufacturers, and their experience shows that frequently too large a capacitor rating was used. The following undersirable conditions have been known to occur:

(a) In some cases, the voltage due to self-excitation rose to 200 per cent, causing failure of motor insulation, indicating lamps, and other devices.
(b) In several instances, the motor coupling and shaft were damaged when too large a capacitor bank was used and the motor was switched by a reduced-voltage autotransformer-type starter.
(c) In other instances, motors have been damaged from overload because allowance was not made in the overload setting for the reduction in line current due to the capacitor.
(d) In addition, instruments and meters connected in the current-transformer secondary circuit have been damaged by overvoltage.

The purpose of this article is to study these problems and their solution. A useful application table is included which lists the maximum capacitor rating for use with motors and the reduction in line current with the recommended capacitor rating. The latter information is useful for selecting the proper overload-relay setting.

Overvoltage Due to Self-excitation.

Self-excitation refers to the action of an induction motor operating as an induction generator with excitation supplied by capacitors. Such excitation may occur when the switch is opened and the running motor is disconnected from the power source, or when the motor is driven by an external means.

The mathematical theory of self-excitation is involved but only a simplified graphical solution is given here. If resistance is neglected, self-excitation will occur when

$$X_C \leqq X_L$$

where X_C = capacitive reactance

X_L = magnetizing reactance

(A small value of X_C corresponds to a large capacitor kilovolt-ampere rating). For practical purposes $X_C = X_L$ when the capacitor kilovolt-ampere rating is equal to the magnetizing kilovolt-amperes of the motor. This is very nearly the reactive kilovolt-amperes or kilovars at no load.

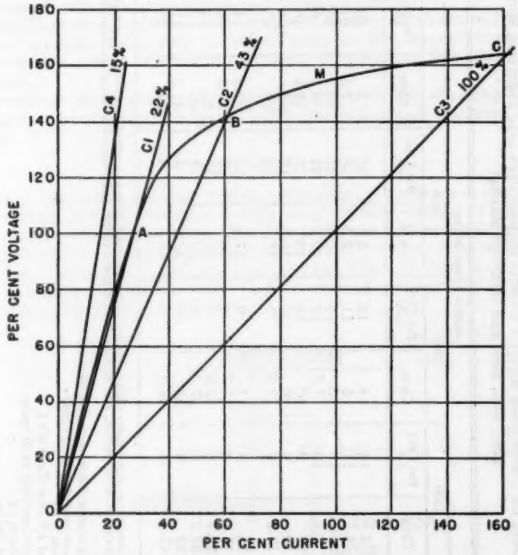


Fig. 1. Typical motor-excitation curve and capacitor volt-ampere characteristic curves. These provide a simplified graphical solution to problems involving self-excitation

Curve M of Figure 1 shows a typical volt-ampere characteristic of a motor. Point A indicates the per cent magnetizing current at no load and normal voltage. Curves C1, C2, C3, and C4 show the volt-ampere characteristcis of capacitors having various ratings. All capacitor curves falling below the motor-characteristic curve M indicate that $X_C < X_L$ (capacitor kilovolt-amperes is larger than the motor-magnetizing kilovolt-amperes) and therefore the motor will self-excite. The final voltage of self-excitation, assuming the speed remains constant, occurs when $X_C = X_L$ or at the points where the capacitor curve intersects the motor-characteristic curve (points A, B, and C).

The capacitor curves above the motor curve, such as curve C4, indicate that the capacitor kilovolt-amperes is less than the motor-magnetizing requirements. Hence, the motor will not self-excite. Self-excitation can be measured by connecting a voltmeter across the motor terminals and reading the voltage after the switch is opened.

TABLE I

RECOMMENDED MAXIMUM CAPACITOR RATING WHEN CAPACITOR AND MOTOR ARE SWITCHED AS A UNIT*

Representative Data for Three-phase 60-cycle General-purpose Open-type Induction Motors of 220-, 440-, 550-, and 2300-volt Rating†

Induction Motor Horsepower Rating	MOTOR SPEED IN RPM											
	3600		1800		1200		900		720		600	
	Ckva**	Per Cent AR ††	Ckva	Per Cent AR	Ckva	Per Cent AR	Ckva	Per Cent AR	Ckva	Per Cent AR	Ckva	Per Cent AR
10	2.5	9	4	11	4	12	5	17	5	23	7.5	28
15	2.5	9	5	11	5	11	7.5	16	7.5	21	10	26
20	5	9	5	10	5	11	7.5	15	10	20	12.5	24
25	5	9	7.5	10	7.5	10	10	14	10	19	15	22
30	7.5	9	10	9	10	10	10	13	12.5	18	15	21
40	10	9	10	9	10	10	12.5	12	15	16	17.5	19
50	12.5	9	12.5	9	12.5	9	15	12	20	15	22.5	17
60	15	9	15	8	15	9	17.5	11	22.5	14	25	16
75	17.5	9	17.5	8	17.5	8	20	11	27.5	13	30	15
100	22.5	9	22.5	8	22.5	8	25	10	35	12	37.5	14
125	25	9	27.5	8	27.5	8	30	9	40	11	47.5	13
150	32.5	9	35	8	35	8	37.5	9	47.5	11	55	13
200	42.5	9	42.5	8	42.5	8	45	9	60	10	67.5	12

* When manual reduced voltage autotransformer-type starter such as shown in Fig. 2 is used, refer to method described in the text for selecting the capacitor rating if load data is appreciably higher than that of the motor. The motor full-load power factor, with capacitor ratings as listed in this table, will range from 95 to 98 per cent.

† For 50-cycle application the following representative data may be used:

(1). For standard 60-cycle motors operating at 50 cycles
Ckva = Ckva from Table × 1.3
Per cent AR = Per cent AR from Table × 1.1

(2). For standard 50-cycle motors operating at 50 cycles.
Ckva = Ckva from Table × 1.1
Per cent AR = Same as Table.

**Ckva is rated kilovolt-amperes of capacitors connected at motor terminals.

††Per cent AR is per cent reduction in line current due to capacitors and is helpful for selecting the proper motor-overload setting when the overload relay is located as shown in Fig. 5.

Curve C2 of Figure 1 applies where the capacitor kilovolt-amperes is sufficient to improve the motor full-load power factor to 100 per cent. It should be observed that the voltage of self-excitation is 143 per cent. Depending on the motors, this percentage will vary and may be considerably higher for some types.

In the usual motor application, the motor slows down rapidly after the switch is opened and the voltage rapidly decreases. A 15 to 20 per cent reduction in speed eliminates self-excitation sufficiently to cause the voltage to collapse in a few seconds. However, in a few cases with high-inertia loads the voltage of self-excitation has been sustained for several minutes.

The graphical solution described assumes that the frequency of self-excitation is equal to the power-system frequency. This is approximately true in most cases since the frequency of self-excitation corresponds to the motor speed, which approximates synchronous speed.

Overvoltage may be reduced by means of a series or shunt resistance in the capacitor circuit. Generally, however, such devices are not used because of the continuous losses or the complication of switching the resistor to avoid the losses.

Overvoltage alone may not be the sole criterion for selecting the amount of capacitors to use; the listings of Table I consider both transient torque and voltage.

Transient Torques.

When a running induction motor, with shunt capacitors is connected to a power source, a high transient torque may be devoloped. This may occur when a motor is transferred to the line from the reduced-voltage tap of an autotransformer-type starter (Figure 2). Such a torque may occur also when a running motor temporarily is disconnected from its line, and the starting switch is reclosed while the motor is still running and maintaining voltage at its terminals by self-excitation.

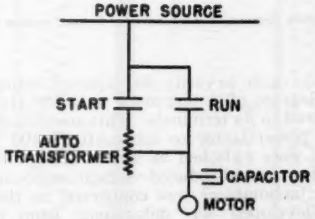


Fig. 2. Diagram showing the location of a capacitor and a reduced-voltage autotransformer-type starter in a motor circuit

To produce transient electrical torques, the motor voltage developed by self-excitation must be of appreciable magnitude and it must be out of phase with the line voltage when the switch is closed. This torque is similar to that caused by connecting together two synchronous generators which are out of phase.

If there is no load connected to the motor shaft, the torque will be absorbed by the motor inertia and will result merely in the motor's momentary acceleration or deceleration of but a few cycles duration.

On the other hand, if the inertia of the load connected to the shaft is appreciable, some of the torque will be transmitted by the shaft to cause acceleration or deceleration of the load. If the load inertia is several times the inertia of the motor rotor, most of the transient electrical torque will be transmitted as

transient mechanical torque by the shaft and coupling. In some cases this has caused fractured couplings and twisted shafts.

The peak value of the electrical torque is determined primarily by the magnitudes of the line and motor voltage, the electrical angle between them, and the reactance and resistance of the motor. High transient torques are accompanied by high transient line currents. The transient torque is of an oscillating character, lasting only for a few cycles and usually having its maximum value in a decelerating direction. The values of peak torque obtainable for a typical motor are shown by Figure 3.

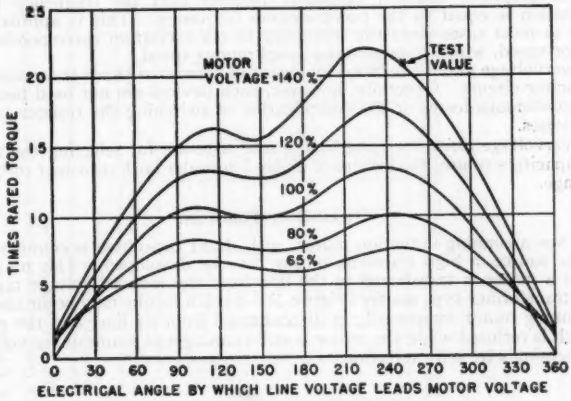


Fig. 3. Curves showing peak electrical torque versus switching angle

A series of tests was made to verify the expected values of transient torque. Figure 4 is an oscillogram of a test made on a 100 Hp. motor with 40 Kva. of capacitors connected to its terminals. This amount of capacitors improved the full-load motor power factor to substantially 100 per cent. The motor and capacitor bank were switched as a unit from reduced voltage to full voltage by means of a manual reduced-voltage autotransformer-type starter. No load (except a tachometer) was connected to the motor shaft. The maximum torque developed was determined from measurement of the maximum rate of motor speed change and a calculated value of motor inertia.

In the case shown in Figures 3 and 4, there was a delay of approximately 0.7 sec from the time the motor was disconnected from the 65 per cent autotransformer tap until it was connected to the line. During this interval, the motor voltage built up to 138 per cent by self-excitation and became about 252 degrees out of phase. The resulting high torque is apparent from the rapid momentary deceleration of the motor after transfer to the line. The measured torque was 21 times rated torque. This measured value is plotted on Figure 3, from which the good agreement between calculated results and test results can be seen.

To prevent transient mechanical torques from damaging the shaft and coupling, the peak mechanical torque should not be permitted to exceed about six times normal. In general, if the connected capacitor kilovolt-amperes does not exceed the value given by Table I, excessive torques will not result from switching occasioned by the use of either electrically or manually operated reduced-voltage starters. However, if manual switching is employed, and the load inertia is appreciably higher than that of the motor, exessive shaft

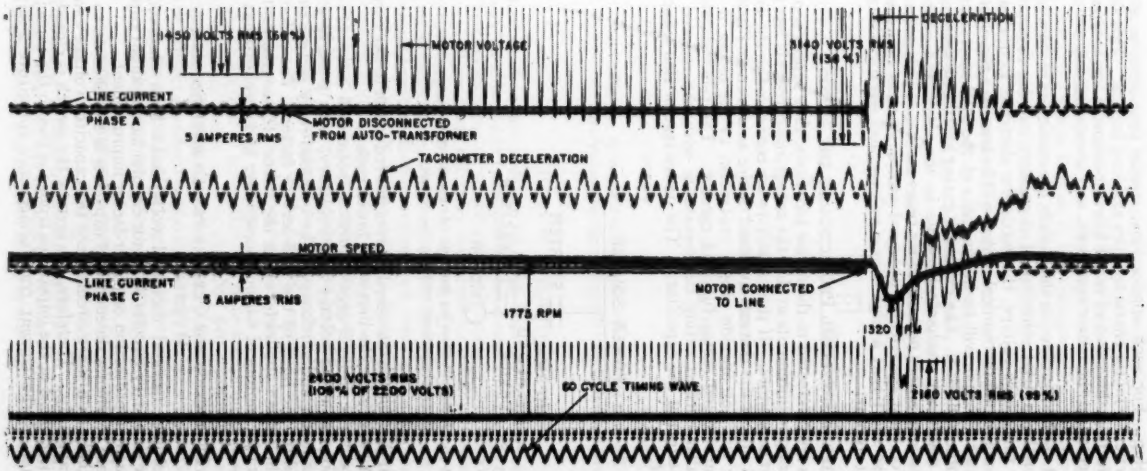


Fig. 4. Oscillogram of test for transient torque of induction motor with shunt capacitors

Motor Rating: 100 hp, 1800 rpm, 2200 volts, 24 amp.
Capacitor Rating: 40 kva.
Motor started with manual reduced-voltage autotransformer starter. No load connected to motor shaft.
Maximum electrical torque =21 times motor rated torque. (From slope of speed trace and motor inertia.)
Tachometer deceleration trace not used, since peak went off film. This trace was obtained from oscillograph element in series with capacitor across tachometer. Harmonics in this trace are due to commutator ripple and slight misalignment in tachometer coupling.
Line-voltage trace was obtained from special circuit which shows only the peaks of the voltage wave.

torques may develop. For such applications, special consideration should be given to the particular motor characteristics and load inertia. This should be done before selecting the value of rated kilovolt-amperes for a capacitor that is to be connected to the motor terminals, and simultaneously switched with the motor.

By the graphical method outlined in this article, the maximum motor voltage from self-excitation by a trial selection of capacitors can be determined. From Figure 3 for this motor voltage, the maximum electrical torque can be determined. The maximum mechanical torque will be less than the electrical torque; the mechanical torque will be in the ratio of the load inertia to the total inertia of motor and load. The capacitor rating should be selected by trial so that the maximum mechanical torque in the shaft and coupling, determined in this manner, does not exceed six times normal. This procedure is not necessary for most electrically operated motor starters because the switching time is so short that a high motor voltage and electrical angular difference does not appear.

Thermal-overload Protection of the Motor.

When capacitors are connected to the motor terminals, they supply some of the motor-magnetizing requirements so that the actual line current is less than it would be without capacitors. If the capacitors are connected to the motor starter on the load side of the thermal-overload device as shown in Figure 5, the overload relay will not provide proper protection to the motor if it is selected for the uncorrected motor full-load current. The relay should be selected for a smaller current rating commensurate with the reduced line current due to the effect of the capacitors. The percentage of this reduction is shown in Table I.

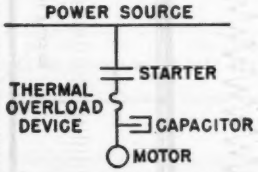


Fig. 5. Diagram showing location of capacitors and thermal-overload relay in the circuit

It should be noted that for the low speed motors this reduction in line current is rather large, particularly for the motors of lower rating.

The standard open-type squirrel-cage induction motor will carry 115 per cent of the rated load at rated voltage and frequency, with possible slight differences in power factor and efficiency. The overload-relay setting therefore can be selected on the basis of the 1.15 service factor. The reduction in current as listed in Table I applies for either the 100 or 115 per cent loading. Examination of data for motors of various horsepower and speed ratings has shown this to be true.

Overvoltage Protection for Current-transformer Secondary Windings.

Excessive overvoltages (several thousand volts) have been observed in current-transformer secondary circuits of motor circuits having shunt capacitors for rotating-machine protection or power-factor improvement.

Referring to Figure 6, when a de-energized capacitor is switched on to the bus, it appears initially as a short circuit since the capacitor voltage cannot be changed instantaneously. Therefore, the instant the switch is closed the system voltage is distributed in the impedance from the bus to the capacitor. Since the impedance of the current transformer may constitute a major

portion of this circuit impedance, it may assume the major part of the voltage drop.

The voltage as viewed from the transformer secondary winding will be increased by the turn ratio. The magnitude of this voltage also will depend upon the volt-ampere burden in the transformer secondary circuit; the larger the burden in volt-amperes the higher the voltage. The amount of capacitance at the motor terminals has very little effect on the magnitude of the voltage.

Many types of protective devices can be used in the current-transformer secondary circuit, such as a shunting resistor, cutout, or filter. Very effective protection is provided by a Thyrite by-pass device which is connected across the current transformer secondary and which limits the magnitude of the overvoltage. This does not cause any objectionable error in secondary current within the operating range.

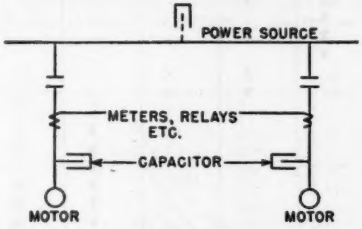


Fig. 6. A diagram of a circuit arrangement that will produce overvoltage in current-transformer secondary circuit

Basis of Application Table.

How much capacitance can be safely applied? The recommended capacitor ratings listed in Table I are selected conservatively for the motor and its drive.

The overvoltage due to self-excitation usually will be within the maximum value (110 per cent) normally permitted for continous motor operation. The transient torque occasioned by the use of reduced-voltage starters will be held to a reasonable value, with the possible exception of the applications involving a manual autotransformer starter and cases where the load inertia is appreciably higher than the motor inertia. Special application procedures for both of these exceptional cases have been outlined in foregoing paragraphs.

The no-load power factor will be approximately 100 per cent and the motor full-load power factor will range from 95 to 98 per cent, which gives sufficient power-factor improvement in most cases. The capacitor rating will range from 20 to 40 per cent of the full-load motor kilovolt-amperes. The smaller value applies to the high-speed motors which inherently have a higher power factor than low-speed motors.

For the purpose of simplicity, the data are confined to a single table for the most common motor sizes in the 220-, 440-, and 550-, and 2300-volt rating. Some of the capacitor kilovolt-ampere values given in Table I do not conform to the present standard capacitor ratings for all voltage classes; in such cases the next lower standard rating should be selected. The standard capacitor ratings for the common voltage classes are given in Table II.

Individual-motor Power-factor Improvement Versus the Group-capacitor Method.

The use of a common motor controller for switching the motor and the capacitor as a unit has become increasingly popular because it eliminates one switching device and because of the operating convenience. The capacitor is

TABLE II

STANDARD CAPACITOR RATINGS FOR THREE-PHASE 60-CYCLE UNITS

Capacitor Kva	INDIVIDUAL UNITS			STANDARD RACK-TYPE EQUIPMENTS*		
	Volts			Volts		
	230	460 and 575	2400	230	460 and 575	2400
0.5	x	..	..	..	..	..
1.0	x	x	..	..	..	..
2.0	..	x	..	..	..	..
2.5	x	..	..	..	..	..
5.0	x	x	..	..	..	..
7.5	x	..	..	..	..	..
10.0	..	x	x	..	..	..
15.0	..	x	x	..	..	..
15	..	..	..	x	..	..
30	..	..	..	x	x	x
45	..	..	..	x	..	..
60	..	..	..	x	x	x
90	..	..	..	x	x	..
120	..	..	..	x	x	x
135	..	..	..	x	..	..
180	..	..	..	x	x	x
240	..	..	..	..	x	..
270	..	..	..	..	x	x
360	..	..	..	..	x	x

* Standard rack type equipment as commonly used for group-capacitor installations. Larger banks are available for 2400-volt service if more capacity is required. This listing is for standard racks of full capacity. Unit may be removed in 7.5-kva units for 230-volt service and 15-kva units for 460-, 575- and 2400-volt service.

switched in and out of service with its associated motor and therefore tends to eliminate overvoltage usually associated with light-load conditions in a plant. This unit-switching arrangement is economically attractive when only a few motors are involved or when there is no diversity among motors. For the opposite circumstance, such as is common in industrial plants with a large number of motor-driven equipments, improvement of power factor by the use of group capacitors automatically switched in several steps is usually more economical than an equivalent amount power-factor improvement accomplished by the application of capacitors to individual motors. Operation with automatic control results in the functional equivalent of individual-motor power-factor improvement since the capacitors may be switched in blocks as dictated by the load requirements. Several articles have appeared recently describing various types of control and their application for automatically switching capacitors.

Numerous studies were made to determine the relative economics of plant power-factor improvement by means of capacitors with individual motors and the group-capacitor method.

The price comparisons were on the basis of the same amount of total power-factor improvement. For example, when all motors are simultaneously connected to the line, so that the motor-diversity factor is 1, the capacitor kilovolt-amperes required is the same for the two methods. When only 50

per cent of the motors are operating simultaneously, corresponding to a motor-diversity factor of 2, the group-capacitor rating need be only 50 per cent of the total capacitor kilovolt-amperes connected to all motors. The motor-diversity factor is the total motor-connected horsepower as related to the total horsepower of motors in operation.

The price ratio of individual capacitors to group capacitors was almost equal for the 220-, 440-, and 550-volt equipments for the same percentage of motors on the bus so that the average price ratio for this voltage range was used. The price data were based on standard noninflammable liquid-filled capacitors used for power-factor improvement.

Example 1: Power-factor Improvement of Individual Motors Versus Group Method of Power-factor Improvement for Service Below 600 Volts.

The price ratio of individual versus group capacitors for typical plants with motors from 3 to 50 Hp. is shown on Figure 7, plotted as a function of the per cent of motors in operation.

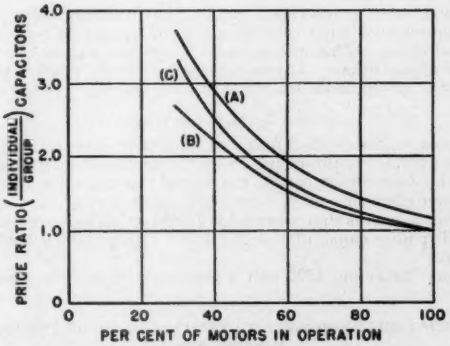


Fig. 7. Price ratio $\left(\frac{\text{Individual}}{\text{Group}}\right)$ capacitors versus per cent of motors in operation (for service voltages below 600 volts)

Curve *A*: Group capacitors with manual switching
Curve *B*: Group capacitors with automatic control and switching
Curve *C*: Equal capacitor cost in dollars per kilovolt-ampere for individual-motor and group-capacitor methods

From curve A of Figure 7 it should be noted that the group-capacitor method with manual switching is more economical than the individual-motor method even for the 100 per cent condition when all motors are in operation. The reason is that the price of capacitors in dollars per kilovolt-ampere is higher for small units than for larger units, such as are commonly used with the group-capacitor method.

Curve B shows the price ratio when the automatic control and switching feature is incorporated with the group-capacitor method. (This is the operating equivalent of the individual-motor-capacitor method.) It should be observed that even with the automatic control feature the group-capacitor method is economically more attractive than the individual-motor method.

Curve C shows the price relationship on the basis of the same capacitor cost, in dollars per kilovolt-ampere, for the two methods. This curve also clearly indicates the effect of diversity in the motors that are operating.

Curve A will be very nearly correct for all applications. Since low-voltage manual-switching devices are inexpensive, they represent but a small part of the total capacitor-equipment cost. Curve B is representative for medium- and large-size industrial plants. For small plants or plants having a small connected motor load, the price ratio will be lower since the cost of the automatic-control and switching feature becomes a large part of the capacitor-equipment cost when small capacitor banks are used. Generally, however, the automatic-control feature is not necessary in the small plants.

Example 2: Group Capacitors for Diversified Motor Load and Individual Capacitors for Selected Large Motors for Service Below 600 Volts.

In those aplications involving a large number of small motors and some large motors it is good practice to use group capacitors for the diversified motor load and individual capacitors for selected large motors. Large motors require large capacitor units which have a low unit price approaching that of the group-capacitor method. A low diversity factor among the large motors favors the individual method of power-factor improvement. If the motor-diverstity factor is greater than about 1½, the group-capacitor method is generally more economical.

The combination of group capacitors for the diversified load and individual capacitors for selected large motors offers the operating benefits associated with unit switching. This arrangement helps prevent over-voltage during light-plant-load conditions. Consequently, automatic control usually is not required for the group capacitors used in such cases.

Example 3: 2300-volt Service.

The group-capacitor method may not be economically attractive for 2300-volt (or higher voltage) equipments unless the motor-diversity factor is greater than 1½ to 2. One reason is that the cost of the capacitor-switching device, usually a power circuit breaker, is an appreciable part of the total equipment cost. Another reason is that motors for 2300-volt service are usually 100 Hp. or larger and require capacitors of the larger ratings which have a relatively low unit cost.

Applications involving 2300-volt equipments should be considered individually.

Considerations Favorable to Individual-motor Power-factor Improvement.

Capacitors are automatically switched—Capacitors will be connected only when needed and therefore will minimize plant-voltage rise at no load.

Application engineering is simplified—Capacitor rating can be selected from Table I.

Flexibility is provided for plant rearrangements—When plant changes require rearrangement of equipment, the capacitor and motor can be moved together, thus insuring proper power-factor improvement of the motor at any location.

Installation is simplified—The capacitor and motor starter may be placed in a unit housing.

Considerations Unfavorable to Individual-motor Power-factor Improvement.

Price is higher for equipments below 600 volts—The price comparisons shown in Figure 7 are on the basis of actual selling price and not on the installed basis. If the installation cost were included, the relationship would probably be even more unfavorable to the individual-motor method since, generally, many small units cannot be installed as cheaply as a few large racks in a group. This is particularly true when the type of equipment furnished for group-capacitor installations is shipped complete as a unit ready for service. Even though the unit-type capacitor and starter is used, which does not require any additional installation expense for the capacitors, the group-capacitor method is cheaper.

Involves poor use of investment—This condition is true when all motors are not operating at the same time. In the average industrial plant only 25 to 75 per cent of the motors are connected to the bus at any given time.

Lacks interchangeability of motor equipment—Usually 220-volt motors can be reconnected for 440 volts but capacitors cannot. It is possible to use a 460-volt capacitor on 220 volts but such a condition results in approximately 25 per cent of the rated kilovolt-amperes. A 230-volt capacitor cannot be used with a 440-volt motor, although two 230-volt capacitors can be connected in series for 440-volt motor service.

Limitations in location—Capacitors for power-factor improvement of 5- to 25-Hp. motors for 220-, 440-, or 550-volt service are relatively large compared with the motor. This may necessitate giving special consideration to their location and mounting. However, this limitation may be avoided if the capacitor is located in the motor starter.

Improvement in over-all plant power factor is limited—Power-factor improvement of individual motors has the limitation of improvement of the motor load only. The full-load motor power factor is improved from 95 to 98 per cent for the capacitor values recommended in Table I. If additional power-factor improvement is necessary for the plant, the additional capacitors required should not be switched with the motors. With the group-capacitor method, the entire plant power factor may be improved to the desired level.

Conclusions.

(1) In applying shunt capacitors to the terminals of induction motors for power-factor improvement, care should be exercised in selecting the capacitor rating to avoid:
(a) Overvoltage due to self-excitation.
(b) Transient torques.
(c) Overvoltage in current-transformer secondary circuits.
(d) Improper motor-overload protection.
(2) The data in Table I are a practical guide in selecting the amount of capacitors to be switched with a motor.
(3) Generally, economic considerations favor the group-capacitor installation for plant power-factor improvement when the service voltage is below 600 volts, the individual motors are small, and the motor-diversity factor is large. For other conditions individual comparisons should be made. For maximum operating benefits the group-capacitor method usually will consist of several blocks of automatically switched capacitors.

PROBLEMS CONNECTED WITH RECLAMATION OF WORN PARTS BY THE METAL-SPRAYING PROCESS.

The paper below was written by W. E. Ballard, A. I. Mech. E. The article with its introduction is reprinted from the June 1945 "Journal and Proceedings of the Institution of Mechanical Engineers".

In times of peace the salvaging of worn parts is not usually a major problem confronting the mechanical engineer. Every consideration is given to new materials and to novel designs, but except for those engaged on works maintenance, the returning of old parts to service has not in the past received enough attention from professional engineers. In war time, however, the repair of damaged material becomes a national duty.

Although metal spraying by the wire process has become more widely known during the past two decades, the number of engineers who would feel competent to judge its suitability for any repair is comparatively small. The object of the present paper is to describe certain matters of interest to engineers in connection with this form of salvage. It is not proposed to give details of metal spraying tools, or pistols, as descriptions of these may be consulted in the technical press. For the same reason an account of the many

parts normally repaired by this method is omitted. Metal spraying is being used commercially to a very large and increasing extent for reclamation work. To assist engineers faced with the problem of repairing a worn part, the author has arranged the paper in the form of answers to the following questions: (*a*) Is metal spraying a suitable method of reclamation? (*b*) If so, how must the work be prepared for spraying? (*c*) What method of spraying and which metal should be used? (*d*) What finish is necessary?

(*a*) Is Metal Spraying a Suitable Method of Reclamation?

The deposit of metal obtained by spraying has a peculiar structure. Each particle, as it reaches the surface to be treated, flattens out, and the final deposit is therefore a conglomerate of small bodies which resembles the result of piling large numbers of saucers indiscriminately together, with all but a few lying horizontally. The edges of the particles are irregular, and it is the interlinking of these irregularities which binds the units together in the mass. This structure can, of course, be modified by subsequent treatment, but that will largely militate against the advantages of the method and is, therefore, not usual. The piled structure must be taken into account in practice, and it will be seen that in such a conglomerate, the strength will differ slightly when considered in relation to the applied force, but in any event it will not be high. Untreated deposits obtained by spraying are not in themselves strong enough to add strength to a reclaimed part, and therefore in specifying metal spraying, the engineer has to satisfy himself that the worn part is in itself strong enough for further duty. If this is not so, some other method must be used.

It will be seen, moreover, that the structure of sprayed metal will cause it to be very weak if the thickness is reduced to too great an extent. The finished coating should be at least 0.015 inch thick. This may necessitate the further reduction in size of the part to be treated, and therefore the strength of the part must be considered not as it is when taken from service, but when it is ready to receive the deposit.

The bearing surface of a shaft represents the ideal job for reclamation by spraying and it is of no importance whether the working speed is low or high. During the short time which elapses while each layer of the coating is built up, a certain amount of contraction occurs, and this serves to tighten the metal on to the shaft. If the surface to be built up is flat, this contraction still operates, and unless precautions are taken, it will tend to loosen the deposit at the edges. When building-up an internal bore the contraction tends to draw the deposit away from the shell, so a special technique is required. The process of spraying need not cause any large increase of temperature; loss of temper of the part is therefore avoided, and the areas of weakness which usually surround welds do not exist. Owing to the nature of the structure, the deposit is not usually regarded as ideal under conditions of impact, and it is not possible to build new splines on shafts. Generally, if both the bearing surfaces of a shaft and of the bearings are worn, it is preferable to build up the shaft and to leave the internal diameter of the bearing oversize, rather than to build up both the bearing and the shaft.

It is not usual at present to build up faces which are to be screw-threaded, as the structure of the deposit tends to give rather friable threads. While it is comparatively simple for a skilled operator to build up complete bores of small size, say 1¼ inches to 2 inches diameter, it is difficult to make a job or half-bearing shells which are less than 4 inches in diameter. It may seem that the limitations suggested give a very restricted field to repairs by spraying, but this is far from the case. Badly worn journals are by no means rare, and they are easily repaired by spraying. Pump shafts, too, are often discarded when they might have been easily repaired by spraying. Sometimes, when corrosion is a contributory cause of the damage, stainless steel may be deposited instead of the more ordinary non-alloy steels.

The engineer naturally asks whether (if a part be suitable for reclamation from the point of view of its factor of safety) the repair can be expected to give reasonable service, and whether there is any advantage in the curious structure of sprayed metal? Returning to the simile of the pile of saucers, it can be

visualized that however closely the units lie together, there will be spaces between some of them, and that these spaces will be in part interconnected. This is true also of sprayed metal, especially in deposits of metals, such as steel, with high melting point. Measurements of porosity have been made by many investigators, but published results may often be misleading because the porosity depends on the closeness of the piling and this is in turn dependent on actual spraying conditions. Nevertheless some porosity is always present in sprayed coatings of metals of high melting point. Shaw (1937) shows that this porosity allows the deposit to become impregnated with oil, and also produces a surface containing minute pores which exude oil in service. This results in a perfect retention of the oil film on lubricated surfaces, and reduces wear to a minimum. Under partially lubricated conditions the advantage is more marked, as breakdown of the oil film is long delayed.

(*b*) How Must the Work Be Prepared for Spraying?

There is always a temptation on viewing a worn part to consider only the more obvious portions of the damage and gauge all the work to be done from this inspection, but in the case of a shaft the worn portion may be reduced by, say, 0.040 inch on the diameter at the point of maximum wear, the diameter gradually increasing on either side of this point until the unworn portion is reached. If this be so, the shaft must be turned or ground 0.030 inch under the original diameter throughout the whole length of the part to be reclaimed. If this is not done, the deposit thickness will decrease until it amounts to only a few thousandths of an inch. A weakness must develop in such circumstances, and will result in the breaking away of flakes.

If the reduction is made some way along a shaft, it is sometimes advisable to undercut slightly the vertical face at the limits. This procedure is quite sound, as it allows the sprayed metal to be dovetailed into the base; but if this method is used, it is necessary first to fill the undercut by direct spraying. If this is not done and the spraying is allowed to follow the normal layer on layer principle along the length of the repair, the undercut is likely to collect the very fine metal dust generated from the first passes. This dust may subsequently be covered with metal, and in service such a metallic crust will break away Although it has been suggested that this is due to excessive carburization of the metal at this point, the trouble is found to be entirely mechanical.

The reduction to a suitable size for spraying is a simple operation in most cases; but where hardened shafts are encountered, difficulties may arise, and it may be necessary to resort to turning with "Widia" tools, or to grinding.

Having prepared the part for deposition as far as size is concerned, the next point is a consideration of the surface for receiving the sprayed metal. There is no "line-up" between sprayed deposits and the base metal, and adherence can only be obtained by the application of the particles in the spray to a suitably roughened surface, the surface itself also being free from grease. The right surface is usually obtained by shot-blasting with angular steel grit. The pressure of the blast and the size of the abrasive to some extent depend on the hardness of the surface to be treated, air pressures of 30-60 pounds per square inch being normal, whilst the grit should pass a sieve having from 15 to 30 meshes per inch. There is a tendency in war time for producers of steel grit to admix a small quantity of fine round shot with the angular grit, but this is to be deprecated as the presence of the round particles tends to flatten the irregularities of the prepared surface. Methods of preparing the surface to be sprayed by means of chemical or electrochemical treatment are not very successful, and can be ignored commercially at the present time.

The adhesion of the deposit to the base depends on a form of mechanical interlocking and will, therefore, have a maximum value for each surface produced. On a flat surface the adherence will be less than on a shaft where a complete ring of metal is deposited, for in the first case it will depend only on the interlinking of the particles with each other and with the interstices of the base; whilst in the second, the effect of shrinkage at the moment of impact will be added to the intermeshing. It is extremely difficult to produce

test pieces which will give figures free from criticism when subjected to mechanical loading, and it is therefore not desirable to attempt to evaluate the actual limits of adhesion. All that can be said is that practice has proved it to be high enough for most purposes.

Another method of surface preparation in common use today has the advantage that it can be carried out in a machine shop without additional plant; it consists merely in roughening the surface by means of a screw thread of from 20 to 30 threads per inch and about 0.03 inch deep. The thread is cut as roughly as possible so that the apex of each thread is torn. One method of achieving this is to allow the tool to chatter a little by mounting it below center, but adjustment of tool profile and cutting speed will bring about similar results. The deposit adheres well to such a surface, provided that all traces of lubricant are removed—if necessary by the application of a degreasing agent such as trichlorethylene.

It has been stressed throughout the paper that much of the work of reclamation is carried out on shafts, and it is also quite certain that in many cases these shafts are highly stressed. The trend of modern research has been to indicate that surface irregularities, especially when sharply defined, give convenient starting places for the commencement of fatigue cracks. Since becoming interested in this matter, the author has made extensive inquiries and has come to the conclusion that fatigue failures from this cause are not so frequent as is often suggested. This may be due to the excellence of the average stressed part and the ample safety factor allowed, but it would be extremely interesting to have the results of a statistical survey of the incidence of fatigue cracking from this source. It will be readily understood that the fear of this difficulty held back the preparation of surfaces by rough-threading in this country, although it was freely practiced in America. Gradually, however, users of the spraying process began to adopt this system and its use is increasing. The author has not yet heard of a single failure by fatigue cracking of any part so treated. One would have expected that after five years of service, some evidence of the bad effects of rough screw-threading would be available. It would appear, therefore that further research may show that the importance of surface blemishes has been exaggerated.

The preparation of flat surfaces is sometimes carried out by producing a surface resembling the rough thread by means of chippers, either electric or pneumatic. Carefully carried out, this method gives good results and is very useful where shot-blasting is out of the question.

(*c*) What Method of Spraying and Which Metal Should Be Used?

All reclamation work using such metals as steel and nickel is achieved with the gas-fed pistol, using the metal in wire form. Tools using electric heat, generated as an arc, are often described in the technical press, but as yet there seems to be no indication that the gas pistol is likely to have serious competition, because it is easily controlled and gives a uniform deposit of known properties. Moreover, it produces these deposits with reasonable speed and economy. The wire pistol has four feeds:—

(1) The metallic wire.
(2) A combustible gas under pressure.
(3) Oxygen from cylinders.
(4) The compressed air blast.

It is obvious that some alteration of the type of coating produced may result from a variation in the feed of the air or the gases, or in the rate of presentation of the metallic wire. To these variables may be added at least two others, namely, the distance of the tool from the job and the movement of the tool in relation to the surface of the work. Briefly, it has been found that increasing nozzle distance increases porosity and oxygen content; and a large consumption of the gases increases oxidation. Although, for a skilled operator working in laboratory conditions, it is easy to alter the type of coating to suit the job, it would be too much to expect the ordinary operator to do this, and in these circumstances makers of metal-spraying tools as a rule

design their equipment to strike a general satisfactory value, and each tool will give a good average performance if used as recommended by the suppliers.

There is, however, a very sharp difference between English and American practice in this direction. The average English metal-spraying pistol is designed to use wire 1½ or 2 millimeters in diameter, and with steel, to give a deposit of about 5 pounds per hour. The average American pistol always uses wire upwards of 2 millimeters in diameter, and deposition rate is at least twice that suggested by English practice. It is, therefore, desirable to examine this difference critically. It has been proved that there appears to be an optimum point at which the amount of oxygen in the coating and the amount of porosity imparted are in "equilibrium". If conditions are varied to give a different coating, the percentage porosity may diminish as oxygen content increases, and vice versa; but this point of balance will be slightly different for coatings of a coarse texture from that for coatings of a fine texture.

English practice has aimed at producing coatings with the finest possible texture at the greatest possible speed, and at designing tools which will, in the hands of an ordinary operator, give a coating with a mean value of oxygen content and porosity. It has been found that this can only be achieved with a medium rate of deposition. American practice has developed along rather different lines in that endeavors have been made to produce metal-spraying pistols which will deposit a maximum amount of metal in the smallest interval of time. To do this it is necessary to add more heat to the melting flame, which can only be done by increasing the volume of the flame and the amount of gas fed to it. To accommodate the volume of the flame it is necessary to open out the annular ports carrying the propellant blast of compressed air which surrounds the flame, and as a result the angle of the pistol nozzle becomes less sharp. To get a fine spray under these conditions it is found better to use more air at slightly higher pressure.

Unfortunately it has not been found possible to produce, by the high-speed pistol, the type of structure aimed at in England. In this country it is felt that it is better to err on the side of slow deposition and to get a technically balanced coating; and it will be of interest to note whether, in process of time, any commercial failures will be ascribed to too high a rate of deposition. Both here and in the U.S.A. continuous endeavors are being made to improve the type of coating by various means. It has been suggested on many occasions that a better coating might be produced by the substitution of a neutral gas, such as nitrogen, for air as the propellant. Sillifant (1937) indicates that in the spraying of steel the use of nitrogen as the propellant gives a less oxidized coating. While, under the condition of spraying noted by Sillifant, this is perfectly true, it is equally true to state that, provided that the modern metal-spraying pistol is used correctly, it can be made to produce an equally unoxidized coating, while still employing air as the propellant.

Experiments have proved that a large proportion of the oxidation which takes place in the modern spraying tool occurs as the particles reach the surface to which they adhere, and a comparatively small proportion of the oxidation is due to conditions in the pistol flame or to chemical action while the particles are in flight. For this reason it is important that the work being sprayed should not be allowed to increase its surface temperature unduly. It is rightly claimed that metal spraying should be regarded as a "cold" process; and if large areas are covered, or if the pistol is moved rapidly over the surface, little or no temperature rise takes place. Building up for reclamation is often done in a lathe, and the metal-spraying pistol takes its place on the tool post. The feed is quite slow, and in these circumstances, unless care is taken, the amount of heat dissipated by the air blast is not sufficient to keep the surface of the job really cool. It is therefore advisable to have extra air jets or even jets of water directed on to the work near the point where the spray of metal impinges. In this way oxidation is minimized, and there is no distinct advantage in the use of inert gases. If the metal-spraying tool is used correctly it is not a matter of importance whether the fuel gas be hydrogen, acetylene, propane, or coal gas, only slight adjustments being required in the nozzle to give the best results with a particular fuel.

For reclaiming worn bronzes, bronze wire may be used, the composition being as nearly as possible that of the parts to be built up. Where this is not possible, a phosphor bronze wire seems to give excellent results. Most engineering parts requiring reclamation involve lubricated steel surfaces. Every type of steel wire has been suggested for this purpose. Many engineers still think that wear is reduced to a minimum if the surface is extremely hard, but this is not borne out in practice. For instance, crankshafts which have been coated with intensely hard chromium deposits have not been entirely successful, the difficulty being that intensely hard deposits do little to maintain the essential oil film. It seems rather doubtful, at the present stage of knowledge, whether intensely hard deposits having a porous nature (such as is obtained by spraying high carbon steel and then chilling) show any distinct advantage over softer deposits obtained by the use of ordinary mild steel. Medium-carbon steel wire (0.7 per cent carbon) gives very good results and a fairly hard coating. High percentages of carbon, of course, increase the hardness; and if the carbon content is about 1 per cent and the job is kept very cold, a chilling effect becomes noticeable and coatings can be produced which are ground only with difficulty.

The author has seen a good deal of work done with ordinary mild steel wire, which has given perfect service in every way in very difficult circumstances. It must be assumed, therefore, that in regard to the choice of wire, it is not the type of metal which matters, but the ability of that metal to maintain the oil film. One advantage of using medium-carbon steel, as compared with a mild steel, is that the larger proportion of carbon tends to reduce the chance of high oxygen content if the operator is not efficient. Occasionally fine hair cracks develop during the grinding of the metal-sprayed surface; these are due either to an excess of oxygen being used in the flame or to the surface of the work being allowed to get too hot. With a medium- or high-carbon steel wire such cracks are less likely to occur, even if the operator is not very skilful in controlling the flame.

In America it has been suggested that special steel wire containing small quantities of chromium and nickel give excellent results, particularly with regard to the machining properties. No such very distinct advantage has been proved, in the author's opinion, but the claim is worthy of note. In the case of pump spindles mild steel wire may often be replaced by a stainless chromium-nickel steel wire of "18/8" weld decay-proof steel, which produces a coating not only resistant to corrosive influences but also able to maintain the oil film.

Although reference has been made throughout the paper to lubrication by oil, it would seem that the same remarks apply to apparatus lubricated by water. For instance, the ram of a hydraulic stretching machine, which was copper-covered by the electrolytic process, gave continual trouble owing to the leathers wearing out, with frequent scoring of the copper deposit. Some years ago when the copper deposit was finally removed and replaced by sprayed copper this trouble completely disappeared and the leathers have lasted an astonishingly long time and no scoring has taken place. This is probably due to the fact that the leathers cannot remove the last films of water from the travelling surface of the copper, and therefore that surface is always lubricated with water.

(*d*) What Finish Is Necessary?

The normal finish of metal as sprayed is matt. With a pistol correctly adjusted the matt surface has a rather satin-like appearance and should not be definitely rough. Nevertheless, it would be impossible, when building up by metal spraying, to ensure that the final surface, as sprayed, would be within reasonable limits of tolerance in regard to dimensions. It is, therefore, usual to build up the sprayed coating so that it is a few thousandths of an inch greater than the desired dimension and then to reduce to size, usually by grinding. If high-carbon steel has been used as a deposit and the spray has been at all chilled, it will be too hard to be treated by any type of cutting tool. The grinding of metal-sprayed coatings does not really call for any special

comment, except that the most satisfactory stone appears to be medium bauxite with a vitreous bond, using suds as lubricant. The speed should be 5500 feet per minute, and the pressure on the stone should not be great. It would be unfair to suggest that the metal-sprayed deposit can be ground as easily as the metal in its massive state as there is always a tendency for the stone to glaze more rapidly when dealing with sprayed metal. This may possibly be due to a certain amount of oxide in the coating, which produces small but very hard inclusions. The glazing of the stone is not excessive and is usually about 25 per cent more than in grinding ordinary material. To the eye, the ground surface is not different from the surface of ordinary steel, but under a magnifying glass the minute porosities which hold the oil can be seen. These porosities are perhaps more noticeable in the case of nickel or stainless steel coatings which, after grinding, are sometimes polished. It is not usually possible to obtain, on a metal-sprayed coating of the harder metals, a "mirror" polish. But when depositing softer metals, such as zinc or aluminum, the small porosities are covered by the flow, and a mirror finish can be obtained quite easily. When the metal spray is medium-or low-carbon steel it is possible to finish by turning, and that this is best done by using a boron or tungsten carbide tool and employing a low surface speed (usually about 70 feet per minute) and very light cuts.

It is often suggested that the sprayed deposit should be case-hardened or heat-treated in some way. Such treatment is unnecessary and may lead to serious failures. It has been proved that at the temperature at which re-crystallization of the metal can take place, the normal expansion of metals with increasing temperature gives place to a rapid contraction in the case of the sprayed metal. For instance, sprayed copper commences to contract rapidly at 600 degrees C. (1112 degrees F.) because the reorientation of the crystals tends to fill the porosities in the deposit, with a subsequent decrease in volume. This is disastrous if the coating completely encircles a shaft, as fracture must obviously occur. Therefore, if very hard deposits are necessary, high-carbon steel should be sprayed and the surface kept chilled. Chromium wire is not available, so chromium coatings cannot be deposited by wire spraying.

SHARPLES OIL PURIFYING PROCESSES.

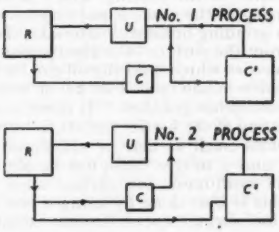
A description of a method of treating lubricating oil to insure maximum purification with the employment of disc-type centrifugal separators reprinted from the July 1945 issue of the "British Motor Ship".

Sharples centrifugal separators employing disc-type bowls may be considered an unusual departure, the machines to which most users have been accustomed being fitted with tubular elements. Three bowls provided with discs are illustrated in the accompanying diagrams, which are adapted from the illustration which accompanies a patent specification (565,713) communicated by the Sharples Corporation, Philadelphia, to the representative of a British firm of patent agents. The top left-hand diagrams indicate the processes used in the special method of separation which it is proposed to carry out.

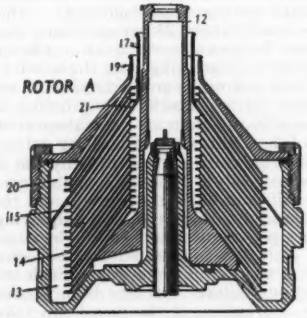
The coarser and heavier impurities, for instance, are removed from a large flow of the oil and the finer particles from a lesser flow during each operation. This is accomplished by dividing the rotor and directing the oil so that the large flow passes theough one part and remains under centrifugal force for a relatively short time, the small flow being dealt with by the other part and subjected to a more prolonged centrifugal action. The discs with the wider spacing in the first portion of the rotor permit large particles of sediment to be removed without jamming in the discs or the feed holes, while the second part of the bowl has closer spacings, permitted by the previous removal of the coarser impurities.

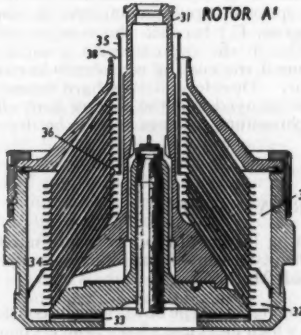
Referring to the diagram showing No. 1 process, the contaminated oil is taken from a tank (R) and subjected to partial or non-rigorous centrifugal

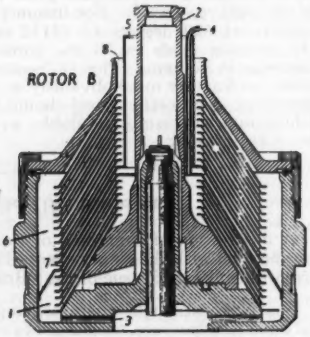
action in a zone (C). The second step of centrifugation (C^1) represents an attempt to remove practically all the finer impurities by retaining the liquid in the rotor for a much longer period than in the first step (C). The purified oil from both steps is passed to the engine (U), where it becomes contaminated and is returned to the reservoir (R) for repurification.



Sharples centrifugal separator with disc-type bowl.







In explaining the process, it is assumed that there is a maximum permissible quantity of fine impurities amounting to 0.3 per cent and the increase is 0.05 per cent in use, at each interval. This may involve the passage of all the oil through the first step (C) and 25 per cent through the second step (C^1). If a thorough removal of the fine impurities occurs in the latter step, the quantity unremovable in the former will gradually increase until it reaches 0.15-0.20 per cent. After a condition is reached when the oil contains 0.15 per cent and this oil accumulates 0.05 per cent of additional fine impurities during its re-use, it contains 0.20 per cent upon the next passage to the purifying system. Since 25 per cent of the oil is passed through the second step (C^1) and all the fine impurities are removed, the percentage extracted from the total flow is 25 per cent of 0.20 per cent, or 0.05 per cent, i.e., the exact percentage accumulated since the last treatment. When this stage is reached, there is no progressive increase in the proportion of finer impurities in the system.

In the event of employing No. 1 process, according to the diagram, rotor (A) or (A^1) is used. Rotor (A) has a central feed (12) through which the oil

is passed to the bottom of the lower zone of centrifugation (13), fitted with frustoconical stratifying discs (14). The main body of the liquid, after the removal of impurities by centrifugal force, passes to the center of the rotor. A partition (15) separates the zone (13) from the upper zone (20). Restricted passages (21) determine the proportion of the liquid passed to the upper zone, where the impurities pass outwardly to the circumference of the rotor. The purified oil is discharged through the space between the bowl neck (19) and an extension (17) of the partition (15).

Rotor (A^1) has a feed tube (31) which directs the liquid into a zone (32) at the lower end, where the heavier fluid impurity is discharged from the rotor through passages (33) in the base. With this type of machine the major part of the liquid, partly purified, is discharged up the tube (35) surrounding the feed pipe (31). A minor proportion of the oil passes through spaces (36) in the partition (34) to a secondary zone of centrifugation, where a lengthier purifying treatment removes the finer impurities. Thus, the more thoroughly purified liquid is discharged from the zone (37) through a passage (38).

ALTERNATIVE METHOD OF TREATMENT.

In No. 2 process, the liquid removed from the reservoir (R) is divided into two streams before being subjected to purification. One stream, comprising the major portion, is passed to a zone of centrifugation (C), where it is subjected to treatment at high capacity for the purpose of removing the coarser impurities. The second stream undergoes more intensive treatment in the zone (C^1) before being recombined with the first separated stream. Rotor (B) is used with this process.

The first feed is taken through a tube (2) to a lower zone of purification (1), passages (3) being provided for the discharge of liquid impurities. Purified oil from the lower zone is delivered through a pipe or pipes (4). The second and minor portion of the liquid is fed through a tube (5) into the upper zone (6), divided from the lower zone by a partition (7). In the upper zone the fluid undergoes a prolonged centrifugation and in a purified state is discharged through a space (8). The streams delivered from the upper and lower zones (1, 6) are combined for re-use, as the diagrammatic sketch of No. 2 process indicates.

GREASES FOR THE BUREAU OF SHIPS.

This article, written by Lt. F. A. Christiansen, U. S.N.R., and reprinted from the March 1945 issue of the "Institute Spokesman of the N.L.G.I." gives a brief description of the various greases used by the Navy and lists the applicable specification numbers.

At the present time the Bureau of Ships is meeting most of its shipboard grease requirements with the following types of greases:

(1) Cup grease, specification 14-G-1
(2) Ball and Roller Bearing Lubricant Specification 14-L-3
(3) Graphite grease, specifications 14-L-12 or VV-G-671
(4) Turret Roller and Pinion Lubricant 14-L-8
(5) High Temperature Lubricant 14-L-7

With the exception of Turret Roller and Pinion Lubricant, most grease manufacturers make the other four types of lubricants. In saying "types" it is not to be inferred that most manufacturers have products that meet the requirements of the specifications as written.

The mineral lubricating grease purchased under Navy Department Specification 14-G-1 requires a lime soap and oil of 125 seconds minimum Saybolt Universal Viscosity in NLGI penetration grades 1, 2, and 3.

Graphite greases purchased under Bureau of ships Ad Interim Specification 14-L-12 (INT) and Federal Specification VV-G-671a(1) have the same requirements as the mineral grease just described and in addition, two to

three per cent of graphite having a graphitic carbon content of 95 per cent minimum. The necessity for using these graphited greases aboard ship to the extent that they are being used at present is in question. It will be appreciated if those present here and those interested in graphited greases will contact the Bureau of Ships in person or by letter to describe the applications where graphited greases are indispensable.

Ball and Roller Bearing Lubricant purchased under Bureau of Ships Ad Interim Specification 14-L-3 (INT) is a mixed base, soda-lime soap grease in NLGI grades 1, 2, and 3. Oil viscosities at 100 degrees F. for each of the three grades in order are (1) 150-250, (2) 200-300, (3) 250-350. The calcium oxide content determined on the ash must be between 0.1 and 0.5 per cent.

Some misapprehensions exist as to the suitablity of 14-L-3 greases for electric motor applications. Investigations by qualified men have shown that the grease is performing satisfactorily and that the operating personnel of some ships cause motor failures by overlubrication. No failures were reported due to underlubrication. One ball-bearing failure epidemic in fire and bilge pump motors was found to be caused by poor design rather than grease oxidation. In general, grease lubrication maintenance practices aboard ship are satisfactory except where the appearance of grease brand names appears in maintenance manuals supplied with equipment, but more will be said of this later.

The program underway to use motors whose bearing temperatures exceed 90 degrees C. has brought about the revision of Specification 14-L-7 (INT), High Temperature Lubricating Grease. Copies of the revised specification will be available in November. The specification is essentially the same as Army-Navy Aeronautical Specification AN-G-5a (to be issued soon) except that Bureau of Ships will not require water resistance. Water resistance is a desirable feature and will eventually be included in the specification when it is ascertained that sufficient supplies will be available for both aircraft and shipboard uses. The primary simulated service requirement of the new 14-L-7 specification is that the grease satisfactorily lubricate a No. 204 ball bearing when the bearing is rotated at 10,000 Rpm. and the temperature is maintained at 300 degrees F. for 300 hours operating time, rotation being stopped and the bearing cooled to room temperature after each 22 hours of operation. It is hoped that eventually a high temperature ball and roller bearing lubricant specification covering a single grade will replace the present three grades of 14-L-3 and the one grade of 14-L-7.

Turret Roller and Pinion Lubricant purchased under Bureau of Ships Ad Interim Specification 14-L-8(INT), recently revised, requires an NLGI grade 1 grease having extreme pressure properties and the ability to adhere to a vertical surface. It must also protect steel from corrosion in humid climates. There is no composition limitation in the specification.

Bureau of Ships Specification 14-L-4(INT) for Universal Gear Lubricants is dormant at the present time and purchases are being made under US Army Specification 2-105A.

Bureau of Ships Specification 14-L-5(INT), Non-Slick, Waterproof Lubricants, is also a dormant specification pending completion of a survey being made to determine the necessity of having such a material. The specification in its present form provides for a grade 4 grease which is too hard for general submarine outboard lubrication. It is probable that the specification will be cancelled and superseded by Navy Department Specification 14-L-11 for waterproof grease applications requiring a grade 4 grease and superseded by specification 14-G-1 for applications requiring a softer grease.

The Engineering Experiment Station is at the present time conducting work toward the development of a specification for plug valve lubricants which must resist water and 100-octane gasoline.

Bureau of Ordnance Specification O.S. 1350 entitled "Bearing Grease for General Use in Naval Ordnance" covers a grease having good low temperature properties and is used quite extensively on ordnance equipment and in a few applications other than ordnance equipment to obtain the advantage of its good low temperature properties on equipment mounted topside.

General Purpose No. 1 Lubricant covered by specification 14-L-9 (which is identical to U. S. Army Specification 2-107) is used primarily on automotive equipment and landing craft and is not used for general shipboard machinery lubrication.

General Purpose No. 2 Lubricant intended for wheel bearing lubrication is likewise not a shipboard lubricant. Specification 14-L-10 covering this product is being revised to conform to the revision being made in U. S. Army Specification 2-108. The important changes in the revision are (1) increase of melting point to 300 degrees F. minimum, (2) requiring a soda soap and allowing a small amount of aluminum or lime soap not exceeding 10 per cent of the total soap content and (3) insolubles determination to be made using petroleum ether and eliminating the use of carbon bisulfide.

Waterpump Lubricant No. 4 under specification 14-L-11 is likewise identical to the corresponding U. S. Army Specification 2-109 and is used on landing craft and automotive equipment primarily.

The Bureau of Ships is gradually eliminating any reference to brand names of lubricants in instruction books for individual items of equipment and is requiring their replacement by Navy Specification product. All petroleum manufacturers and their salesmen and lubrication engineers are requested to cooperate in this program. If Navy equipment manufacturers request lubricant recommendations for instruction books, the suitable Navy types should be specified.

If the proprietary name of a product appears in an equipment maintenance manual and that manual becomes approved without eliminating the brand name, operating personnel may relubricate with the wrong type or grade of Navy grease which in turn may result in equipment breakdown. Anyone who knowingly has any part in allowing the appearance of that brand name in place of the Navy designation is more responsible for that failure than the man who put the wrong lubricant in the equipment.

Then there is the case of the instruction book which says to use long fiber grease, medium fiber grease, short fiber grease, and universal joint grease. The activity requiring these may not know what Navy types are applicable and so will order them by the instruction book description. The requisition will get to a Supply Officer who will attempt to assign a Navy type grease without any information available on which to base his decision and his decision can easily be wrong. The receipt of such a requisition can also cause a great amount of delay if the supply activity has to wait for technical assistance to ascertain what Navy types are to replace the brand names or texture descriptions.

There have been and still are many equipment manufacturers who have been so thoroughly sold on a particular brand of grease that they shudder at the thought of using any other grease in their equipment. Such an attitude has its advantages for domestic commercial use of equipment in offering better maintenance but to the Navy it only causes confusion.

At this time the Bureau of Ships would like to request from each grease manufacturer present, that he send to the Bureau a list of all the greases he makes including in so far as possible all the rebrands for each grease with enough of a description of each so that the Bureau may determine what Navy type is suitable as a replacement. This information will be held in strictest confidence and used only for correcting instruction books and to answer inquiries from the fleet for replacement products.

As a warning to grease manufacturers the packaging and marking requirements of grease specifications and of contracts are being made more strict and more practical for Naval use. These restictions are brought about through sad experience with leakers and inferior outside packaging receiving more severe handling than it can stand. Both of these have caused repackaging at Naval Supply Depots before overseas shipment could be undertaken and such repackaging uses up extra man hours.

The following is an excerpt from Bureau of Ships Ad Interim Specification 14-L-12 (INT) of 1 June 1944 on packaging, packing, and marking for shipment:

G-1. *Packaging.*—Unless otherwise specified, the subject commodity shall be packaged in 1-pound cans, 5-pound, 10-pound, or 25-pound steel pails, or in drums with an approximate capacity of 100 pounds, as follows:

G-1a. One-pound cans shall be made of special coated manufacturer's terneplate and steel pails shall be made of bonderized blackplate. One-pound cans shall be multiple friction top type. The bottom and ring shall be doubleseamed and compound lined. The sideseam shall be soldered and thoroughly wiped to remove excess solder. The plug shall be multiple friction type expressly made to fit the ring and shall be capable of providing a leakproof closure. Steel pails shall have welded sideseams, bottoms shall be doubleseamed. The top of the body shall be curled outwardly and shall present a smooth rounded surface for contact with the gasket in the cover. The cover with a flowed-in or tubular gasket, shall be of the lug type having a minimum of 6 lugs on the 5-pound size, 8 lugs on the 10-pound size and 12 lugs on the 25-pound size. One-pound and 5-pound containers shall be furnished without handles; the 10 pound and 25-pound sizes shall be furnished with galvanized wire handles of a minimum of 8 gauge and shall be fitted with a suitable wood or metal hand grip. Handles shall be fastened to the sides of the pail by ears or clips securely soldered or welded into position. Containers manufactured of bonderized blackplate shall be coated on the inside with a baked-on enamel which shall neither affect nor be affected by the product packed. The exterior of containers shall be protected from corrosion by the application of a suitable baked-on corrosion-resistant enamel, and when tin content of solder is less than 30 per cent the sideseam of the 1-pound can shall be striped with corrosion-resistant enamel, except that for domestic shipment no exterior coating will be required on terneplate containers. The minimum gauge of plate and approximate size and capacity shall be as follows:

Capacity Pounds	*Diameter Inches*	*Body Height Inches*	*Gauge of Wetal*			
			Body	*Bottom*	*Top*	*Plug*
1	3-3/8	4-1/2	90 pounds	90 pounds	100 pounds	95 pounds
5	5-5/8	5-7/8	28 gauge	28 gauge	28 gauge	.....
10	7-7/16	6-3/8	26 gauge	26 gauge	26 gauge	.....
25	11-1/4	9-3/16	26 gauge	26 gauge	26 gauge	.....

G-1b. One-hundred-pound drums shall conform to the requirements of Interstate Commerce Commission Specification 37D, except that sideseams shall be welded.

G-2b. *For overseas shipment.*

G-2b(1). Unless otherwise specified, 25-pound pails and 100-pound drums shall be shipped without further packing.

G-2b(2). Unless otherwise specified, 1, 5, and 10-pound cans shall be packed in units of fifty 1-pound cans twelve 5-pound cans, or six 10-pound cans in a cleated plywood box, nailed wood box, or wirebound box, conforming to the requirements of Sections V, VI and VIII, respectively, of Navy Department Specification 39P16, except that no waterproof liner will be required. In cleated plywood boxes, no drainage ducts in cleats will be required. Each box shall be strapped in conformance with the requirements of the applicable section of Navy Department Specification 39P16. Cans shall be separated within shipping containers by double face corrugated or solid fiberboard partitions and /or separator pads. Fiberboard shall conform to the requirements for Types V3C or V3S as described in Section VIII of Navy Department Specification 39P16.

That's the way the Navy has specified that grease shall be packed and that's the way the Navy wants it. It is realized, however, that there is a shortage of facilities in the country for making the five and ten pound pails and the Navy will, of necessity, have to take grease packed in containers other than specified. The grease in this instance should be packed in multiple friction top cans. Single friction top or full open friction top cans will not carry the material to its ultimate destination. Even when the multiple friction top can

is used the plug should be soldered into place through the application of solder at three points equidistant around the periphery of the ring. This is necessary because most of the grease is overpacked in wood and the shock transmitted to the cans when the case is dropped pops the plugs resulting in a mess and loss of material. Reports back from overseas indicate that one of the worst packs in the Navy is the grease pack. This condition must be corrected. Not only is it costing money but the Navy loses valuable shipping space, loses material and worst of all loses the services of the equipment on which the grease would have been used had it arrived safely.

The marking requirements are now in the process of standardization for lettering size and colors. Brand names will not be allowed. The specification title of the material will be the largest lettering on the container so that personnel can readily identify the material.

The Bureau of Supplies and Accounts is now purchasing greases for West Coast on and off shore shipments on semi-annual contracts. It is intended that such a procedure will be universally adopted. The advantages to be gained through semi-annual contracts are as follows:

(a) Manufacturers will know their monthly obligations in advance and can purchase raw materials, packages and containers and can arrange their production schedules more easily.

(b) Shipments can be made to transport loading piers directly thus reducing handling by Naval Supply Depots.

(c) Procurement at plants nearer to the point of rail delivery reduces long rail hauls by box car.

(d) Complete and prompt inspection of the product at source will be obtained.

(e) Local purchases can be eliminated.

Everyone wants a general purpose grease including the Bureau of Ships and the development of such a material for shipboard use means saving of weight and space which is constantly sought for other equipment and stores. This general purpose grease should have:

(1) Good oxidation and storage stability.
(2) Good low temperature and high temperature performance.
(3) Good E.P. properties.
(4) Non-creepage for electric motor bearings.
(5) Water resistance.
(6) No objectionable odor.
(7) Corrosion preventive properties.
(8) A grade 2 consistency.
(9) A reasonable price.

Research toward this end is being carried on with petroleum, non-petroleum, and soapless lubricants, and it is hoped that such a lubricant will be developed.

To a few present here, everything stated in this paper is "old stuff". Many of you, however, may find some helpful information for future contacts with the Navy with which, it is hoped, both you and the Navy will benefit.

Remember "Bureau of Ships does not want proprietary names on lubricant containers or in equipment instruction books."

ASSOCIATION NOTES.

Addresses.

It is of paramount importance that each Member keep the Society informed of his current address. In no other way will you be certain of receiving your Journal and other mail.

Annual Meeting and Nominations to Offices for 1946.

The Annual Meeting of the Society was held in Washington, D. C., on Thursday, 2 October, 1945, in accordance with its By-Laws.

The following nominations for offices for the calendar year 1946 were made:

For President:

Rear Admiral Harvey F. Johnson, U.S.C.G.

For Secretary-Treasurer:

Captain F. W. Walton, U. S. N.
Captain J. B. Duvall, U. S. N.

For Member of Council:

Captain F. F. Agens, U. S. N.
Captain W. D. Chandler, U. S. N.
Rear Admiral S. S. Kennedy, U. S. N.
Captain Logan McKee, U. S. N.
Captain Roger W. Paine, U. S. N.
Commander C. J. Palmer, U. S. N.
Commander F. B. Schultz, U. S. N.
Captain G. H. Wood, U. S. N.
Captain G. A. Tyler, U. S. C. G.
Commander H. F. Davis, U. S. C. G.
Commander K. H. Beeson, U. S. N. R.
Captain R. E. Coombs, U. S. C. G. R.
Commander H. C. Shepherd, U. S. C. G. R.
Commander R. T. Simpson, U. S. N. R.
Mr. P. H. Israel.

Mr. F. C. MacKrell.
Mr. R. E. Post.
Mr. J. H. Schombert.

Ballots have been distributed. Polls Close at 3:30 p.m., on Wednesday, 26 December, 1945.

Annual Banquet.

It was unanimously declared to be the sense of the Annual Meeting that the Annual Banquet of the Society be resumed in the spring of 1946.

Membership.

Attention of all non-member officers is especially invited at this time to the advantage and benefit to be attained by membership in this Society. The Society was organized in 1888—for the sole purpose of the advancement of Engineering. Its JOURNAL, published quarterly, In February, May, August and November, and completing its 57th year of continuous publication, has attained a foremost rank in its field and is a recognized authority throughout the engineering world. It is used generally by Naval officers and civilians alike as a reliable reference book. The Bureau of Ships considers the JOURNAL of such value that it makes it available for the libraries of all Naval vessels and shore activities of any size. The presence of the JOURNAL in your personal library can not fail to be of great benefit to you, often making available information of great value which can be obtained from no other source.

It is particularly suggested that officers of the Naval Reserve, who may be contemplating return to civil life, should arrange for membership prior to detachment from active duty.

Annual dues are $5.00, which are probably lower than those of any other technical Society. There is no initiation fee, nor any extra charge for the JOURNAL. This extremely low cost is possible only because the Society is bona fide operated solely for your benefit without any pecuniary profit to any one.

An application blank generally will be found at the back of each copy of the JOURNAL. However, if none is found, application by letter will be accepted.

It is suggested that Members will confer a real favor on non-members by bringing the Society to their attention.

Society Lapel Button.

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine, dignified insignia. It is one-half inch in diameter. The oak leaves and lettering are red on a gold back-ground. It is available to all members at fifty cents (50c) each.

Membership Additions.

The following have joined the Society since the publication of the August, 1945, Journal. Addresses of personnel on ships not given.

Naval.

Alexanderson, Paul A., Jr., Ensign, U. S. N. R.
Anthiw, Stephen, Ensign, U. S. N. R.
Baum, Raymond L., Lieut., j.g. U. S. N. R.
Becker, Pierre Robert, Ensign, U. S. N. R.,
84-59 160 St., Jamaica, L. I., N. Y.
Beckwith, Alfred T., Lieut., U. S. N. R.
Berger, R. C., Ensign, U. S. N. R.
Betts, Dennis Rozzell, Lieut., j.g., U. S. N. R.
Bohon, Edward O., Machinist, U. S. N.
Brook, Charles B., Lieut. Commander, U. S. N.,
201 Westshire Road, Baltimore 29, Md.
Brown, Benjamin B., Lieut., U. S. C. G. R.
Calhoun, Jack R., Lieut., j.g., U. S. N.
Center, Edgar A., Lieut., U. S. N. R.,
43 Lincoln St., Needham 92, Mass.
Child, Richard Wall, Ensign, U. S. N. R.

Collins, Orlyn M., Lieut., U. S. N.
Clark, Warren B., Lieut., U. S. N. R.
Croke, Frederic Lawrence, Lieut., U. S. N. R.
Croke, William F., Lieut., U. S. N. R.,
235 West Hill Ave., Somerset Center, Mass.
DeGalan, Leon B., Lieut., U. S. N. R.,
Falk Corporation Marblehead, Mass.
Dixon, Donald E., Lieut., U. S. N. R.,
3844 40th St., San Diego, Calif.
Dority, Alex O., Lieut., U. S. N. R.,
3545 S. Four Mile Drive, Fort Barnard Hts., Arlington, Va.
Dudley, Robert E., Ensign, U. S. N. R.,
435 McKinley Ave., Kellogg, Idaho
Dunkerly, Joseph L., Lieut., j.g. U. S. N. R.,
194 Arlington Ave., Paterson, N. J.
Edwards, Frederick A., Captain, U. S. N.,
Bureau of Ships, Navy Dept., Washington, D. C.
Farley, Joseph F., Rear Admiral, U. S. C. G.,
Coast Guard Headquarters, Washington, D. C.
Fay, James Alan, Ensign, U. S. N. R.,
345 Molino Ave., Long Beach, Calif.
Fredrick, Jack Rowley, Lieut., U. S. N. R.
Ferguson, Charles E., Chief Machinist, U. S. N.
Forde, Widar J., Lieut., U. S. N.
Fowden, Wilbur M. J., Lieut., U. S. N.
Fuller, Andrew L., Ensign, U. S. N. R.
Glasson, Theodore J. E., Lieut., j.g., U. S. N. R.
Graham, Willard E., Lieut., U. S. N.
Green, Samuel W., Lieut., j.g., U. S. N. R.
Greenberg, Howard R., Lieut., j.g., U. S. N. R.
Haidet, R. P., Lieut. Commander, U. S. N. R.,
Inspector of Machinery, Cleveland Diesel Engine Div.,
General Motors Corp.. Cleveland, Ohio.
Hemmerdinger, Monroe E., Lieut., U. S. N. R.,
Bureau of Ships, Navy Dept., Washington, D. C.
Mail, 407 N. George Mason Drive, Arlington, Va.
Henson, Louie B., Machinist, U. S. N.,
1520 El Camp Drive, Dallas 18, Texas.
Higgins, Harry A., Lieut., j.g., U. S. N. R.,
197 Kilton St., Allston Mass.

Hopkins, Charles E., Ensign, U. S. N. R.,
229 Caledonia St., Lockport, N. Y.
Hybertsen, George N., Ensign, U. S. N.
Hyde, Benjamin D., Lieut., U. S. N. R.,
810 High St., Boston, Mass.
Jaeger, Blaine F., Lieut., j.g., U. S. N. R.
Jamieson, Norton B., Ensign, U. S. N. R.,
14 Jane St., Paterson 2, N. J.
Jones, J. George, Jr., Lieut., j.g., U. S. N. R.,
740 S. Claibourne Ave., New Orleans, La.
Kaltenbach, Earl G., Commander, U. S. N. R.,
Dravo Corporation 300 Penn Ave., Pittsburgh, Pa.
Kaufman, Ephriam, Ensign, U. S. N. R.,
1068 Wilmohr St., Brooklyn 12, N. Y.
Kaufmann, George A., Ensign, U. S. N. R.
Kellam, Harold S., Lieut., U. S. N. R.,
866 Regal Road, Berkeley, Calif.
Kenney, Jack T., Ensign, U. S. N. R.
Knapp, Richard P., Lieut., U. S. N. R.
Lloyd, Lester E., Chf. Mach., U. S. N.,
5215 N.E. 31 Ave., Portland, Oregon.
MacFarran, Ernest L., Lieut., U. S. N. R.,
R.D. No. 5, Auburn, N. Y.
MacIntyre, Thomas N., Lieut. Commander, U. S. N. R.,
1045 Serrill Ave., Yeadon, Del. Co., Pa.
McKinney, Jack E., Machinist, U. S. N.,
Mahoney, James Jerome, Ensign, U. S. N. R.,
438 Forest St., Kalamazoo, Mich.
Masters, W. Lawrence, Jr., Lieut., j.g., U. S. N. R.
Mounts, P. H., Ensign, U. S. N. R.
O'Hare, Don Robert, Lieut., j.g., U. S. N. R.
O'Sullivan, Richard J., Lieut., U. S. N. R.,
4305 Avenue M., Brooklyn, N. Y.
Peterson, Gordon I., Lieut., U. S. N.
Quigley, James A., Jr., Ensign, U. S. N. R.,
18 Lee Ave., Troy, N. Y.
Ramelli, Andreas A., Lieut., U. S. N. R.
Ritchie, Clark A., Lieut. Commander, U. S. N., Ret.,
Navy Yard, Charleston, S. C.
Roberts, Emmett T., Jr., Lieut., j.g., U. S. N. R.
Robertson, Kenneth G. S., Lieut., U. S. N. R.

Salisbury, Chester Riley, Ensign, U. S. N. R.
P.O. Box 93, Colton, Calif.
Saunders, Kelly Hobbs, Lieut., U. S. N.,
108 8th St., Verplanck, N. Y.
Scheuerman, William I., Lieut., j.g., U. S. N. R.,
2019 Braddish Ave., Baltimore 16, Md.
Schultz, Carl E., Lieut., U. S. N. R.
Route 2, Box 28, St. Joseph, Mich.
Scott, John R., Ensign, U. S. C. G. R.,
1622 N.E. Couch St., Portland 14, Oregon.
Seaver, Joseph H., Lieut. Commander, U. S. N. R., Ret.,
223 S. E. 61st Ave., Portland 16, Oregon.
Shippey, Felix A., Commander, U. S. N. R.,
28 Curtis Ave., W. Somerville 44, Mass.
Spirko, Michael, Lieut., U. S. N. R.
Steedley, John F., Jr., Ensign, U. S. N. R.,
Care Post Engineers, Tyndall Field, Fla.
Taussig, Howard L., Lieut., U. S. N. R.,
care Inspector of Naval Material, U. S. N., Harvey, Ill.
Taylor, Richard A., Lieut., U. S. N. R.,
18 Vernon St., Auburn, Maine.
Trefethen, Lloyd M., Ensign, U. S. N. R.,
196 Hillcrest St., Waltham, Mass.
Vaughan, George A., Lieut., U. S. N. R.
Varadi, Louis Ernest, Ensign, U. S. N. R.
Wallin, W. W., Lieut., U. S. N. R.
Wenz, Carl R., Lieut., j.g., U. S. N. R.
Winsch, Charles E., Lieut., U. S. N. R.,
3652 Frankford Ave., Philadelphia 34, Pa.
Woody, Marvin Ames, Elec., U. S. N.,
535 Grand Ave., W., Eau Claire, Wis.
Wolff, Alan Sanford, Ensign, U. S. N. R.
Zuppano, Edward C., Lieut., j.g., U. S. N. R.

CIVIL.

Bayman, R. G., Senior Marine Engineer, Navy Yard,
Charleston, S. C.
Mail, 413 Churchill Road, North Charleston, S. C.
Boyce, William G., Principal Marine Engineer, Navy Yard,
Charleston, S. C.
Mail, 208 Live Oak Ave., Charleston 50, S. C.

Brown, Thomas Walter Falconer,
Research Director, The Parsons and Marine Engineering Turbine Research and Development Association, Walsend-on-Tyne, England.
Crow, George L., Application Engineer,
General Electric Company, Schenectady, N. Y.
Hilton, Roscoe R., Resident Inspector of Naval Material care Also, Lafayette, Indiana.

ASSOCIATE.

de la Llama, Paul III, Ensign Cuban Navy,
P.O. Box 570, Habana, Cuba.
Durlach, Marcus R., Jr., Marine Engineer, Navy Yard,
Charleston, S. C.
Mail, 128 C Ben Tillman, Navy Yard, Charleston, S. C.
Evans, James E., Asst. Section Leader, Machinery Scientific Section, Shipbuilding Div. Consolidated Shipbuilding Corporation, Orange, Texas,
Mail, 408 Cypress St., Orange, Texas.
Kempton, William A., U. S. S. *Nestor.*
Smith, Ernest, Office of Inspector of Naval Material,
San Pedro, Calif.
Mail, 2045 Easy Aven., Long Beach 6, Calif.